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Introduction to the Themed Section: '*Case studies in operationalizing ecosystem-based management*'

Introduction

Operationalizing and implementing ecosystem-based management

Jason S. Link[1]* and Howard I. Browman[2]

[1]*National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Office of the Assistant Administrator, 166 Water St, Woods Hole, MA 02543, USA*
[2]*Institute of Marine Research, Marine Ecosystem Acoustics Group, Austevoll Research Station, Sauganeset 16, Storebø 5392, Norway*

**Corresponding author: tel: + 1 508 495 2340; fax: + 1 508 495 2258; e-mail: jason.link@noaa.gov*

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Introduction

There is now a large literature on the "ecosystem approach", or "ecosystem-based management" (EBM; hereafter the terms are used synonymously, albeit with an emphasis on EBM) for dealing with the myriad issues impacting marine ecosystems. We will forego a treatment of the "what's, why's, and when's" of EBM, pointing the interested reader instead to the many reviews of that extensive literature (e.g. Browman and Stergiou, 2004, 2005; Arkema *et al*., 2006; McLeod and Leslie, 2009; Link, 2010; Berkes, 2012; Link and Browman, 2014). Rather, given our sense that EBM is moving—albeit slowly—from the "what's, why's, and when's" to the "how's" of operationalization and implementation, it seemed timely to develop this article theme set (TS). The objective of this TS is to advance EBM by offering practical examples of its implementation—or attempts at such—in a variety of incarnations and at various scales, including what has or has not worked, suggestions for best practice, and lessons learned.

The degree to which EBM has been implemented, or not, varies considerably at regional, national, and international levels. Part of this variability stems from how EBM is perceived (see Link and Browman, 2014), which depends upon where one works—in terms of geography, ocean-use sector emphasis, and disciplinary focus—and what role one has—as a researcher, manager, stakeholder, etc. Therefore, we aimed for a wide range of perspectives in this TS in an attempt to capture at least some of this variability to stock-take EBM implementation. We hope that the eight articles in this TS, described below, contribute to and advance the ongoing discussion of the issues surrounding EBM implementation.

The articles in this TS

Marshak *et al.* (2017) note there is a convergence of understanding of EBM across many of the groups listed earlier, implying that inconsistency in the perception of EBM may be less of an impediment than it was, even a few years ago. Instead, the main impediments quantified by Marshak *et al.* (2017) centered on knowledge generation, communication of and about EBM, and governance frameworks established to deal with multisectoral issues. Similarly, Oates and Dodds (2017) reiterate that stakeholder engagement was absolutely critical in operationalizing EBM in the Celtic Sea, particularly as it pertains to the Marine Strategy Framework Directive (EC, 2008, 2010). As both Oates and Dodds (2017) and Marshak *et al.* (2017) note, clear, consistent and continuous communication with all parties is key. These authors also identified the need to measure all salient facets of the ecosystem that are germane to management needs, while recognizing that identifying and agreeing upon these can pose challenges.

Zador *et al.* (2017) report on indicators used to inform the management of living marine resources in Alaska. The list of practical lessons learned, in terms of how to develop and use indicators, should prove relevant elsewhere. Indeed, these lessons resonate with those learned from analogous efforts (e.g. Hobday *et al.*, 2007; Shin *et al.*, 2010), but represent one of the few examples of management practices being changed as a result of the broader ecosystem context revealed by indicators. Incorporation of ecosystem information into ocean-use management is an ongoing process that is not yet fully and quantitatively integrated. Zador *et al.* (2017) provide an example of how such information can be informative, even if not fully treated quantitatively, and note that even qualitatively this is no less powerful or informative.

In terms of protocols to operationalize EBM, Harvey *et al.* (2017) highlight practical lessons from the application of Integrated Ecosystem Assessments (IEAs) in the United States. As a delivery and vetting mechanism for analytical products of ecosystem information, the IEA process seems to be emerging as one of the more flexible and appropriate approaches for conducting EBM. Harvey *et al.* (2017) note that the lack of clarity in how IEAs are related to and can be used to operationalize EBM, and the need for clarity in the use of ecosystem-related terminology, remains a major challenge. Harvey *et al.* (2017) also call for clear governance structures, particularly fora for the uptake of ecosystem information, as have others (e.g. Dickey-Collas, 2014; Samhouri *et al.*, 2014). They also emphasize the importance of scalability (spatially, especially with respect to governance of nested jurisdictions), something that is often understood but not always made explicit. Harvey *et al.* (2017) also note the need to ensure that analytical products and outputs are specifically tailored to the governance or management needs under consideration.

Cormier *et al.* (2017) also reinforce the need to tailor analytical products to management needs. Unpacking policy objectives into operational measures are an important part of developing and using indicators to implement EBM. This is comparable to the indicator suite described by Zador *et al.* (2017), but goes somewhat beyond it in attempting to set desirable (from a management perspective) reference levels for these measures. Cormier *et al.* (2017) again emphasize the lack of clarity often seen in governance regarding specific objectives, but emphasize the role of unpacking general policies that is needed in Canada and elsewhere. Although long-recognized as important (e.g. O'Boyle and Jamieson, 2006), the uptake of these more operational, "unpacked" measures remains limited. Cormier *et al.*'s speculations about the challenges that are limiting this uptake echo other works in this TS, and will resonate with practitioners attempting to implement EBM.

Llope (2017), and Bryhn *et al.* (2017), emphasize attempts to implement EBM in specific regions and across multiple ocean-use sectors. These are at scales much smaller than Large Marine Ecosystems. Again, both struggled with appropriate governance fora, but also with the limited amount of adequate information available at appropriate spatial and temporal scales, competing objectives among stakeholders, and the balance between different interests and obvious tradeoffs. Although no generalized, immediate or obvious solutions emerged, both attempts tabled the issues and discussed them transparently. This latter observation is a major part of operational EBM—accounting for and addressing multiple uses, objectives, and tradeoffs.

Finally, Österblom *et al.* (2017) document how, although governance in Sweden has shifted towards EBM, the political will to enact it in practice remains elusive, possibly because of the multiplicity of competing interests. Yet a detectable shift towards EBM has been seen there, evinced by increasing numbers of proposals for operational practices across ocean-use sectors.

Brief synopsis of the state of EBM

We will close by summarizing the lessons learned from these eight snapshots of the state of EBM and our own overviews of the field.

Clear communication and engagement with all interested parties—particularly non-scientists—is critical. That may not be easy, nor something with which most scientists are comfortable (or have any training with), but where EBM has been attempted, this aspect has been categorically identified as a critical component of success. This comes both from instances that recognized this need *a priori*, and from those in which it was learned the hard way, *a posteriori*.

We recognize that EBM is complex and, therefore, difficult to operationalize. Attempting to characterize, understand well enough, and make decisions regarding marine ecosystems is in itself a Herculean task. Layer on top of that the social, economic, and political considerations that any such management decisions necessarily require makes the task seem nearly intractable. Certainly, the allure of discovery remains, and we cannot monitor and measure all the variables that we would like, but the works herein demonstrate that general theories and principals, and a generic knowledge base, are sufficient to at least bound the scope of tradeoff space needed to implement EBM for most marine ecosystems. A clear set of operational indicators, and associated reference levels for decision support, are rapidly emerging (Shin *et al.*, 2010; Cormier *et al.*, 2017; Zador et al., 2017).

The need to identify a more focused set of governance conditions that better facilitate EBM seems clear. There is no shortage of vague national and international policies, laws, orders, and treaties calling for or requiring EBM (c.f. Browman and Stergiou, 2005; EC, 2008, 2010; McLeod and Leslie, 2009; Link, 2010; Foran *et al.*, 2016; for reviews thereof). These mandates result in various governance structures, frameworks and fora in which ocean-use decisions can be made. Yet, in all of the articles in this TS, the need to clarify objectives and the choices among them, particularly across different sectors and competing interests, consistently emerged as an important consideration for the success of EBM. This is consistent with what others have been communicating for some time (e.g. O'Boyle and Jamieson, 2006; Link, 2010; Dickey-Collas, 2014). A more obvious set of institutional arrangements, mandated demands for increased systemic information and decision-making, fora for the uptake of ecosystem information and ecosystem-level decision-making, and clarity in decision criteria to address tradeoffs among multiple objectives are needed for truly operational, multisectoral ocean use management—i.e. EBM (Harvey *et al.* 2017). Conversely, where EBM has been attempted in a more focused manner, within one or across a limited number of sectors, progress is noteable.

Instances of truly multisectoral EBM remain rare. Although growing, the number of case studies of operational EBM is still limited. We recognize that this TS captures only a few. Nonetheless, our sense from these, and from discussions with our colleagues around the world, is that there is not yet a well-known and widely accepted example of true multisectoral, multiple ocean-use, multi-stressor, multiple driver, tradeoff-evaluated EBM that is fully operational. Certainly EBM has advanced farthest within specific ocean-use sectors. There are some examples that are becoming close to a full EBM operationalization, particularly in the IEA communities of North America and Europe (Harvey *et al.*, 2017; Dickey-Collas, 2014), as well as in parts of Australia. Perhaps this TS, crystallizing the state of the EBM discipline, will spur someone to prove us wrong. We predict that there will be examples of much more fully implemented case studies within the next 5 years.

Finally, although progress towards implementing operational EBM has been somewhat limited, and although EBM is by its very nature difficult, there has been progress nonetheless. The works herein demonstrate that the imperfect steps taken towards operational EBM are better than no steps at all. The attitude of "you have to start somewhere" holds. As each of the works herein demonstrates, attempting EBM generates and encounters barriers and challenges, which then become more clearly articulated, such that solutions can be proposed and tried, and then the process iterates.

We trust that the science executed, and the management based upon that science, will continue to evolve and improve as we collectively sort out what it means to actually do EBM in practice. We hope that the articles in this TS will spur on even further operationalization of EBM.

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Contribution to the Themed Section: '*Case studies in operationalizing ecosystem-based management*'

Review Article

The ecosystem approach in the Gulf of Cadiz. A perspective from the southernmost European Atlantic regional sea

Marcos Llope[1,2]

[1]*Instituto Español de Oceanografía (IEO), Centro Oceanográfico de Cádiz, Puerto Pesquero, Muelle de Levante, 2609 PO Box Cadiz 11006, (Andalusia) Spain*

[2]*Centre for Ecological and Evolutionary Synthesis (CEES), Department of Biosciences, University of Oslo, PO Box 1066, Oslo, Blindern 0316, Norway*

Corresponding author: Tel: (+34) 956294189, Fax: (+34) 956294232; e-mail: marcos.llope@cd.ieo.es or marcos.llope@ibv.uio.no

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This article considers the major events in recent history, current situation and prospects for developing an ecosystem-based style of management in the Gulf of Cadiz. This particular socio-ecosystem is characterised by a clear focal ecosystem component—the role of the estuary of the Guadalquivir River as a nursery area—that has an influence on the marine ecosystem and at the same time concentrates a number of sectoral human activities. This nursery role particularly concerns the anchovy fishery, which is the most economically and culturally important fishery in the region. As a transition zone between river and marine environments, estuaries are particularly sensitive to human activities, either directly developed within the aquatic environment and its surroundings or further upstream within its catchment area. The particularities of the Guadalquivir socio-ecosystem, with an area of influence that extends as far as the city of Seville, require the consideration of multiple sectors and the corresponding conflicting interests. These include the shipping and tourism sectors, the agriculture, aquaculture, salt and mining industries, and the fisheries and conservation interests. This article aims to give an overview of the high-level policy goals and the jurisdictional framework, scope the sectors involved and describe the pressures and risks of their activities. It will identify conflicting interests relating to different visions of the ecosystem as well as the institutional arrangements that could be used to balance them and finally, put forward a vision for using ecosystem-based information to improve multi-sectoral management decisions.

Keywords: agriculture, aquaculture, dredging, dam, fisheries, Gulf of Cadiz, Guadalquivir estuary, nursery, mining, shipping.

Introduction

An ecosystem approach to fisheries management (EAFM), ecosystem-based fisheries management (EBFM), or ecosystem based management (EBM) are nested concepts that differ in the extent to which a given management regime (e.g. fisheries) can be regarded as an ecosystem approach (Link and Browman, 2014). The ecosystem approach constitutes today the central paradigm that underlies living marine resources policy worldwide (Levin *et al.*, 2009; Patrick and Link, 2015). The overall objective is to manage natural resources in a holistic way, by considering the interacting influences of multiple use sectors on the environment (McLeod and Leslie, 2009; Levin *et al.*, 2009; Link, 2010).

In the European Union, important environmental directives, namely the Marine Strategy Framework Directive (MSFD, EC, 2008), the Water Framework Directive (WFD, EC, 2000), and the Common Fisheries Policy (CFP, EC, 2015), call for this approach. Furthermore, Spain is a member of the United Nations Food and Agriculture Organization (FAO) and OSPAR Commission, and signatory to a range of international agreements that promote the implementation of the ecosystem approach, such as the Convention on Biological Diversity. Theory behind this concept is well developed (Link and Browman, 2014; Patrick and Link, 2015). However, its implementation in Europe with regard to fisheries management is still at its infancy. Apart from a few examples from the Baltic Sea, North Sea, and Barents Sea, where environmental conditions and food web interactions are to some extent considered when carrying out stock assessments (Möllmann *et al.*, 2014; Skern-Mauritzen *et al.*, 2016), European fishery assessments are still largely based on one species, ignoring the wider ecosystem context and impacts.

Integrated ecosystem assessments (IEAs) are useful tools to implement an ecosystem approach to fisheries management (EAFM) and eventually a comprehensive EBM (Rice, 2011). In anticipation of the future demands of applying an ecosystem approach, the International Council for the Exploration of the Seas (ICES) embraced the idea of IEAs and made it a core element of the ICES strategic plan (ICES, 2014). Accordingly, ICES developed a wide network of IEA working groups (Walther and Möllmann, 2014) with various levels of achievement (Dickey-Collas, 2014). Currently, there are IEA groups covering the whole North Atlantic regional seas.

One of the newest IEA groups is the Working Group on Ecosystem Assessment of Western European Shelf Seas (WGEAWESS), into which the Gulf of Cadiz (GoC) falls. This article reviews the current situation of the process of implementing an EBM in the region. Specifically, the aim of this paper is to describe the main components, players, and challenges faced by this socio-ecological system. This includes: (i) the ecological characteristics and focal mechanism, (ii) the legislative framework and the responsible institutional bodies, (iii) the trade-offs between the different sectors and their corresponding pressures, (iv) the institutional arrangements that could potentially be used to harmonize those conflicting interests, and finally (v) a diagnosis of the problems encountered when conflict has arisen.

The GoC

The GoC is a sub-basin between the Iberian Peninsula and the African Continent that connects the Atlantic Ocean and the Mediterranean Sea through the Straits of Gibraltar (Figure 1). The northern half of the GoC is the southernmost Atlantic European regional sea.

The abrupt change in coastline orientation at Cabo de São Vicente creates a discontinuity in the Portuguese-Canary Current Upwelling System, which frees most of the GoC from the tight control of the upwelling regime off Portugal (Fiúza 1983; Relvas and Barton, 2002). This is particularly true to the east of Cabo de Santa Maria, where the influence of the Portuguese upwelling vanishes, the shelf widens and waters here reach the highest temperatures in the region.

The GoC is heavily influenced by the Guadalquivir River, which drains one of the major European catchments areas (650 km, 57 000 km^2) contributing to the area's high productivity (Figure 1). Sediments carried by the Guadalquivir form marshes and wetlands that host a rich diversity of wildlife and are relied upon by commercially valuable species. Estuaries are known for their role as nursery areas for many marine species and the Guadalquivir is no exception (Drake *et al.*, 2002; Baldó *et al.*, 2006; Ruiz *et al.*, 2006; Drake *et al.*, 2007). It is this estuarine factor, where terrestrial and marine processes converge, that makes the GoC a unique case study.

Warm water pool

The presence of the Guadalquivir estuary and marshes together with the tidal forcing generate a pool of warm water off the river mouth during spring and summer (García Lafuente *et al.*, 2006; García-Lafuente and Ruiz, 2007). This feature systematically appears in satellite imagery analyses (Vargas *et al.*, 2003; Navarro and Ruiz, 2006). The tidal forcing and the river flow also contribute to maintaining high nutrient and chlorophyll levels all year round, which is particularly important in the summer, when the rest of the basin is stratified and oligotrophic. These particular conditions make the area off the Guadalquivir the most productive of the GoC (Navarro and Ruiz, 2006).

Figure 1. Satellite view of the Gulf of Cadiz featuring a high turbidity event that illustrates the influence of the Guadalquivir River. NASA MODIS, 12/11/2012. Source: earthobservatory.nasa.gov. NASA image courtesy Jeff Schmaltz, LANCE MODIS Rapid Response Team at NASA GSFC.

Traditionally, the local cyclonic surface circulation pattern described during spring-summer has been put forward as a favourable mesoscale feature with regard to the maintenance of this warm and productive cell (García-Lafuente *et al.*, 2006; Criado-Adeanueva *et al.*, 2006, 2009). See also Garel *et al.* (2016).

Winds, upwelling, and retention

There is a local upwelling regime to the west of Cabo de Santa Maria, which is independent of that of the Canary Current and considered a coastal process with a short time response to changes in the wind regime (Criado-Aldeanueva *et al.*, 2006). Westerlies are the winds responsible for upwellings while easterlies, known as levanters (Dorman *et al.*, 1995), have the opposite effect leading to a remarkable increase in temperatures (Prieto *et al.*, 2009). Furthermore, the westerlies/easterlies regime plays a central role in the continental shelf dynamics of the area, affecting retention within the warm cell. Under westerlies conditions, local upwellings enhance productivity and plankton is confined inside the cyclonic cell. In contrast, levanters would favour oligotrophy and the westward advection of plankton and larvae (Relvas and Barton, 2002; Catalán *et al.*, 2006).

The Guadalquivir estuary

The estuary of the Guadalquivir River comprises the lower course of the river, a 90 km stretch from its mouth to the first dam at Alcalá del Río, and covers an area of 1800 km^2 (Andalusian Water Authority, 2009).

Human interventions have drastically modified the entire system, particularly from the 18th century onwards. From this time several major interventions produced the current morphology: (i) continuous cutting off of river meanders (1795–1983) to preserve its navigability as far as Seville, (ii) drainage and filling of large expanses of marshland (1920s) followed by the establishment of new settlements, (iii) construction of dams (1930) and dikes (1985) for flood control or water diversion and (iv) stabilization of banks. As a result, the original 120 km of the estuary has been reduced to the current 90 km length, the flooded surface by 85% and the total freshwater input by 60% (CSIC, 2010). All these changes resulted in a heavily modified estuary, restricted to a canal where dams control the freshwater flux and marshes are isolated from the main course.

Nursery role

The exchange of material between the fresh water mass and the sea contributes to a nutrient-rich estuary and a high biological wealth. In addition, the high productivity and temperature contribute to make the estuary and adjacent marine waters a nursery ground for several commercial species, such as anchovy, sardine, langostine, or prawn. High abundances of eggs, larvae and post-larvae of these species are found in spring and summer (Drake *et al.*, 2002, 2007; Baldó *et al.*, 2006). This nursery function is the main regulating service the region provides in relation to the GoC fisheries.

As a short-lived small pelagic species, anchovy population dynamics are strongly affected by year-to-year fluctuations in environmental processes. Temperature, winds and discharges from the river have been identified as key factors influencing its recruitment (Ruiz *et al.*, 2006, 2009). Discharges have different effects on the nursery role depending on their volume. Low levels of freshwater discharges constrain primary productivity on the shelf limiting the food supply for juveniles (Prieto *et al.*, 2009) while very high discharges cause salinity to drop below the threshold forcing juveniles to leave the protective environment of the estuary (Ruiz *et al.*, 2009). However, the combination of both natural (weather) and anthropogenic (discharges) effects, plus the timing and volume discharged, results in a broad range of combinations that makes the ecological response of the ecosystem to freshwater inputs be not unequivocal (González-Ortegón and Drake, 2012; González-Ortegón *et al.*, 2012, 2015).

Legislative and jurisdictional frameworks

The associated legislation and governance is rather complex. It involves decision makers at local and international level, a number of regional, national and international protection norms and governance that is fragmented across multiple institutions.

As noted in the introduction, two EU Directives protect the marine (MSFD) and transitional (WFD) water bodies. Additionally, the CFP regulates the fisheries in the GoC. The Guadalquivir Hydrographical Federation (CHG, Confederación Hidrográfica del Guadalquivir) is the governmental body responsible for the management of this basin and consequently of its estuarine stretch. Instituto Español de Oceanografía (IEO) is the institution responsible for the implementation of the MSFD and the CFP directives. CHG and IEO report to the Spanish Government.

The marine protected area

The first comprehensive study of the estuary and neighbouring marine coastal area (IEO, 2005) led to the establishment of a Marine Protected Area (MPA). This MPA was designed to preserve the nursery service due to its importance for the species that inhabit the GoC. It includes one estuarine zone and three marine zones to the northwest of the river mouth (Figure 2). This area overlaps with the warm and productive body of water previously described. Moreover, the Guadalquivir estuary is flanking Doñana National Park (1969) and is also under the umbrella of a number of environmental protection regulations.

The regional government 'Junta de Andalucía' has considerable management control over the estuary and its surroundings (Doñana, MPA). The estuarine water body (CHG) and marine waters (IEO) status are, however, the responsibility of the Spanish government.

Sectoral activities and stakeholders

As described earlier the estuary serves as nursery ground for several commercial species, of which anchovy (*Engraulis encrasicolus*) can be considered the most emblematic, due to its economic and cultural importance. The diversity of activities carried out in the estuary and adjacent areas is very high as are the impacts on its functioning and the extent of its habitat.

Freshwater balance: agriculture, tourism, and discharges regulation

The Guadalquivir marshes are vast plains that are periodically flooded by the river. Their topographic and climatic conditions are ideal for the cultivation of rice (Figure 2). However, their location within an estuarine habitat imposes a saline constraint, which demands a high supply of freshwater.

The lower Guadalquivir has been turned into one of the most important tourist destinations in Spain. This has led to a significant increase in water demand following the process of urbanization.

Agriculture and tourism demand freshwater, which has consequences on the freshwater balance of the estuary. Water supply for irrigation and tourism is one of the main drivers of the timing of the discharges. The irrigation period (April–October) and peak tourist season (mid-June through August) coincides with the dry season, when the natural flow of freshwater is at its lowest.

The Alcalá del Río dam, 110 km upstream from the river mouth (Figure 3) is the most important infrastructure regarding the flow of freshwater into the estuary, contributing 80% of the total (CSIC, 2010).

At present, river discharges are regulated mainly for economic purposes, such as irrigation and/or water supply to urban settlements and hydroelectric power generation. Therefore, human activities impose the timing, frequency and magnitude of the discharges with consequences on the physicochemical conditions of the estuary, which eventually affect its production (González-Ortegón and Drake, 2012) and food web (González-Ortegón *et al.*, 2012, 2015).

Land reclamation: aquaculture and salt production

Aquafarming in salt pans has been a traditional activity since antiquity. In the 1970s aquaculture re-emerged with the exploitation of abandoned salt pans. Aquaculture is now a growing sector (Andalusian Water Authority, 2009) (Figure 3). The sector claims

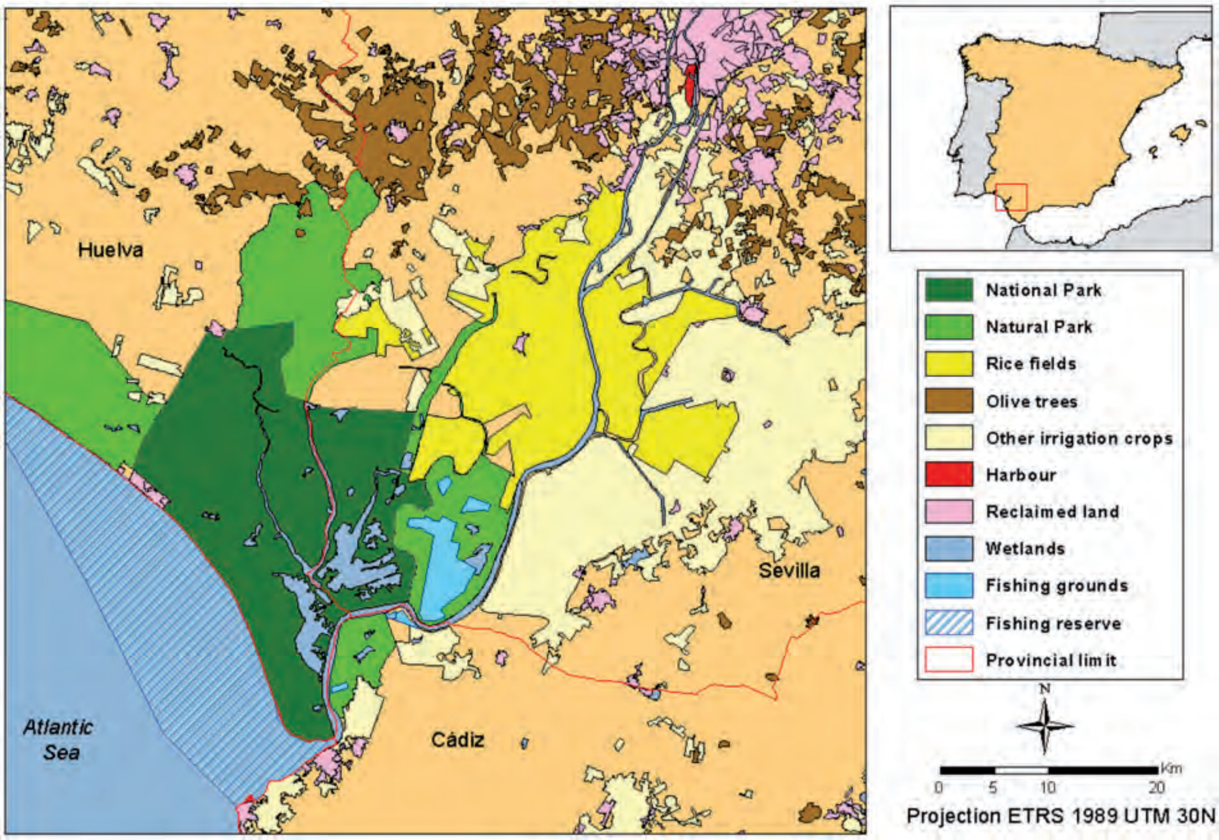

Figure 2. Main water uses in the lower Guadalquivir valley (from Vargas and Paneque, 2015).

that aquafarming does not imply a net consumption of water. But aquaculture facilities are built on previously flooded land. Salt evaporation in ponds is another economic activity in the proximity of the estuary. Some of the land taken by salterns could also potentially return to its primitive state.

Besides this, the activity of the aquaculture and salt industries affects the hydrodynamics of the estuary because of the need to control the propagation of the tidal wave with locks.

Diffuse pressures: shipping and mining

The Guadalquivir River is the navigable gateway to the city of Seville (fourth Spanish city) and the only Spanish river port. To preserve the navigability of the river, major alterations have been performed in the past (cuts off described earlier) and maintenance dredging works are carried out every year.

The Seville Harbour Authority (Spanish Government) is responsible for the management of the so-called Guadalquivir European Waterway (E.62_02). The Harbour Authority is determined to facilitate the access of larger vessels and higher cargo capacity through the construction of major infrastructures. The most controversial of these infrastructures has been a plan to carry out major dredging of the riverbed, which will be reviewed below.

Apart from the ecological alterations derived from the maintenance dredging, shipping poses the risk of accidental spills, the introduction of alien species (Cuesta *et al.*, 1996; Frisch *et al.*, 2006; González-Ortegón *et al.*, 2010) and increases in the erosion of river banks.

Mining is an economically important activity in the Iberian Pyrite Belt and some of these mines lay on the tributary basins of the Guadalquivir. Hence, this activity poses a risk that needs to be considered (see below).

Fishing and conservation

Spanish fishing fleets are organised in the traditional "Cofradías de Pescadores". At a regional level there are those fleets targeting anchovy or several other species outside the MPA, which could be potentially affected by changes in the nursery service. At the local level there is fishing activity within the marine MPA zones. Despite their long-standing tradition, the "Cofradías" are not fully developed in the MPA area. Interestingly, even though the fishermen's organisations are not yet totally functional, women's associations play an active role in speaking on behalf of their menfolk and enthusiastically participate as stakeholders when given the opportunity.

Due to the ecological importance of the area, conservation organisations have a long standing interest in the region. Of particular relevance is WWF and the local SOLDECOCOS.

WWF has played an important role, fiercely campaigning against some of the sector's plans, in particular against the proposed dredging of the river. WWF has a clear agenda for the estuary. This includes an increase in freshwater flows, modification of maintenance dredging, recovery of tidal plains, reconnection of cut-off meanders, improvement of river banks and removal of dikes (WWF, 2012).

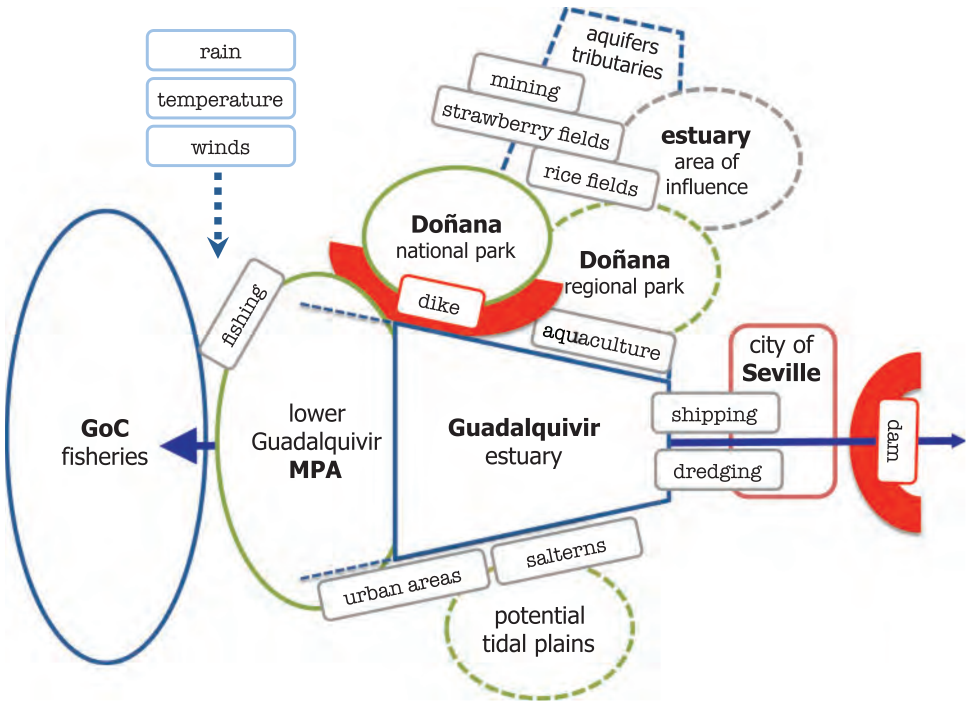

Figure 3. Conceptualized ecosystem. The horizontal blue arrow represents the estuarine gradient, from the lower Guadalquivir MPA, which includes its lower 16 km and the adjacent coastal area, to the upper end beyond the city of Seville. Major infrastructures are shown in red: namely, the "Montaña del Río" dike and the "Alcalá del Río" dam. Sectors whose activities have consequences through tributaries (mining), aquifers (strawberries) or directly on the freshwater flow (rice) are piled up on the upper side. Activities occupying potential tidal plains (aquaculture, salt production, urban areas) are placed on the estuary. Diffuse infrastructures and risks (dredging, shipping) are shown close to Seville. Non manageable environmental factors (rain, temperature and winds) are shown between the sea and the estuary.

SOLDECOCOS (in partnership with WWF) has been closely interacting with the local communities, creating spaces for dialogue and encouraging the organisation of fishermen.

Major events

Aznalcóllar disaster

The first event that had a substantial impact on the general perception of the estuary was the Aznalcóllar mine disaster. In 1998, a retaining dam used to store toxic mining waste at Aznalcóllar broke releasing 4–7 10^6 m^3 of mine tailings consisting of acid sludge and water into the Guadiamar River, which is a tributary of the Guadalquivir (Achterberg *et al.*, 1999). Fortunately, after huge economic investments and a rapid response following scientific guidelines, the mining waste was prevented from reaching the estuary.

As a consequence, a restoration plan called Doñana 2005 was conceived and launched after the disaster. The plan aimed at recovering the natural dynamics of the water and included restoration of marshlands, tidal plains and tributaries, reconnection of cut-off meanders and the permeation of dikes between Doñana and the estuary (Andalusian Water Authority, 2009). It is worth noting that these objectives agree with WWF's current agenda for the estuary (WWF, 2012). The project was never fully accomplished and international organisations (UNESCO, Ramsar, UICN) raised concerns about this lack of commitment. Eighteen years later, the regional government is determined to reopen the mine, not without much controversy and legal problems.

Interestingly, right after the disaster water discharges were increased in order to flux any pollution that could have reached the estuary. This seemingly sensible management action did not consider the implications on the nursery service. That year, anchovy larvae, which are typically found in high abundances in spring were not detected in the estuary until the summer (González-Ortegón pers. comm.). Higher than normal water flow during a key period might have prevented anchovy larvae from entering the estuary.

Dredging

The second and most important event started in 2000 when the Seville Harbour Authority presented a project with the aim of improving the navigability of the river and, in consequence, the size of the ships that could arrive to the port. The project included a major action; the dredging of the river in order to widen and deepen the navigable channel from its current minimum depth of 6.5 m to 8 m. The main argument in favour of such an impacting endeavour was the positive economic consequences, the creation of jobs and attraction of cruise tourists.

The project produced significant conflict between stakeholders and led to the formation of two coalitions. One in favour of the project led by Seville's Habour Authority, trade unions and companies and one against composed of the rice agricultural sector, which feared that an increase in depth would increase salinity and turbidity, as well as conservation associations and Doñana's national park.

In 2005 following recommendations of an environmental impact assessment a scientific committee was constituted to evaluate the impact on the ecosystem. The work resulted in an advisory document (CSIC, 2010) whose final conclusions rejected the projected dredging. Most national public agencies endorsed these recommendations except CHG.

National and international agencies engaged in the debate, including UNESCO's World Heritage Committee (UNESCO, 2013) and the European Commission (EC, 2013). Finally, the project was stopped by the Spanish High Court (Supreme Court, 2015) at the request of WWF. However, the court ruling did not mention 'lack of participation' among the reasons for stopping the dredging works (as mandated by WFD).

The conflict is thoroughly described and analysed in Vargas and Paneque (2015) who stress "the preservation of navigability" as the main concern and driving force regarding any project that could have an impact on the river. Surprisingly, the authors do not mention fishers as having been active stakeholders in the conflict.

At the time of this writing the CHG has commissioned a second environmental impact assessment, which shows its intention to reactivate the plan.

Turbidity

Occasionally, heavy rains and the major discharges which follow result in high and persistent turbidity events. Similar events have also been observed during dry years and seem to be the result of a particular operation of the dam and probably, other anthropogenic processes occurring upstream within the basin (González-Ortegón *et al.*, 2010).

These events affect the estuary and adjacent marine area and are clearly visible from space as illustrated in Figure 1. Three major turbidity events have been recorded since 1997. One of them—November 2007 to June 2008—raised much concern amongst rice producers, and the aquaculture and fishing sectors. As a result, the regional government announced the setting up of an 'interagency commission' with the aim of developing an integrated management of the estuary (Andalusian Water Authority, 2009). Unfortunately, the activity of this multi-sectoral and multi-administrative commission—a clear attempt to establish an EBM arrangement—left little trace.

Ecosystem visions

The three major events described above represented tipping points in the general perception of the estuary. They raised concern and awareness about its current state, resilience and ability to continue to deliver services. Most importantly they led to a clear positioning of the stakeholders that can be used to figure out three ecosystem visions or "ways things should be" paraphrasing Sainsbury and Sumaila (2003).

- The canal vision conceives the estuary as a navigable waterway to the city of Seville. This vision would favour commercial shipping and tourist cruises (Figure 4). It would be compatible with urban development, mining and hydropower generation but confronted by the alternative visions, legislation and policy statements. In addition, this 'way the estuary should be' is more likely to be an unsustainable vision in economic and ecological terms. The CHG is the jurisdictional body closest to this vision. Its organisational chart lists a "discharges commission". The purpose of this board is to advise the CHG regarding the discharges management regime. It could be transformed into a multi-sectoral institutional arrangement in support of EBM.
- The land uses vision perceives the estuary as a productive asset (Figure 4). It challenges the dredging and mining activities and would like to see the frequency and intensity of high turbidity events reduced. It would be in conflict with the healthy ecosystem vision to some extent. Rice producers are represented in CHG board.
- The healthy ecosystem vision conceives the estuary as a degraded and threatened ecosystem that must enhance its functionality and biodiversity (Figure 4). It is in synchrony with the local, national and international legislative frameworks. This vision could be shared to a large extent by both the conservation and fishing sectors. It could, however, collide with some uses and practices developed by the agriculture, aquaculture and salt industries and totally clashes with the canal vision. The MPA advisory board holds fluent dialogue with the fishing sector, scientists and conservationists and is another potential EBM support structure in place.

These two institutional arrangements would appear to have their areas of influence distributed along the length of the estuary. The CHG revolves around the city of Seville and rice fields, while the MPA connects better with those from the lower Guadalquivir and adjacent marine area. No single entity seems to completely incorporate all sectors.

Discussion

Although the ecosystem approach has been formally adopted in fisheries management since the 1990s, tactical management rarely incorporate ecosystem processes. Skern-Mauritzen *et al.* (2016) estimated that only about 2% of world fish stocks incorporate physical or biological drivers in management advice. Interestingly most of these cases are found within ICES, reflecting its efforts to endorsing the ecosystem approach. Remarkably, none of those cases making up the 2% incorporate estuarine processes.

The closest example to the GoC anchovy case presented here is the Bay of Biscay (BoB) anchovy, a European Atlantic stock managed within ICES. Despite the presence of important estuaries in the area (Gironde River), its recruitment does not seem to rely much on these ecosystems. While spawning occurs over the shelf, mainly in the river plumes, juveniles are regularly observed off the shelf. An alternative mechanism by which anchovy may use off-shelf waters as a spatio-temporal loophole of lower predation has been hypothesised here (Irigoien *et al.*, 2007).

The GoC case study analysed here would differ from the above in that estuarine processes need to be taken into account if we aim to implement ecosystem style of management. Estuarine conditions are not the only environmental drivers affecting the ecology of the species. As described above, the wind regime (upwellings, retention) and temperature also play a role, but estuarine conditions are the only over which we can have some sort of control. The simplest and most effective intervention is through the regulation of freshwater discharges.

Vision for using ecosystem-based information

In order to operationalize EBM that help us improve multi-sectoral management decisions it is necessary to select indicators

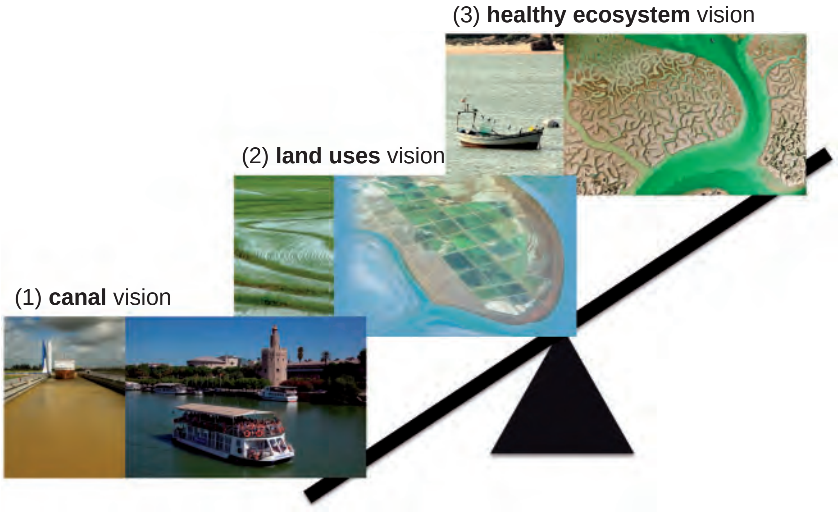

Figure 4. Balance diagram illustrating the three visions of the system: (1) canal, (2) land uses and (3) healthy ecosystem. Panel 1 shows Seville harbour's lock (photo: Julián Rojas, elpais.com) and Guadalquivir tourist boat (photo: Naturanda Turismo Ambiental). Panel 2 illustrates a rice field and Veta la Palma estate, the main aquaculture infrastructure (photo: PESQUERIAS ISLA MAYOR, S.A.). Panel 3 depicts the meandering design of the Guadalquivir wetland's hydrological network (photo: Héctor Garrido/EBD-CSIC) and a fishing boat in the MPA (photo: José Luis Oróñez).

and propose a framework to define reference levels to those indicators. This requires data, models and institutional arrangements.

Data and models

When compared with other European ecosystems where monitoring programs have been running for 30-50 years, the GoC is relatively young (20+). Nevertheless, surveys are in place and the number of models has been growing lately (Ruiz *et al.*, 2009; Torres *et al.*, 2013; Rincón *et al.*, 2016; Carvalho-Souza *et al.*, in prep.).

Of special relevance is the estuarine monitoring programme. This survey has been recording the abundance of fish larvae and plankton in relation to water properties at every new moon since 1997. Several articles describing how the estuarine biological community restructures and responds to climate and discharges have originated from this database (see references above). This long term programme is commissioned by the regional government (co-financed by CFP funds) and its ultimate purpose should be to inform fisheries policy.

Indicators

Indicators are metrics used to determine the state of the ecosystem and to detect changes that occur due to anthropogenic or environmental impacts (Rice and Rochet, 2005). Hence, they are at the interface between science (ecosystem state and functioning) and policy (management alternatives).

Despite the complexity of the socio-ecological system here described, much of it converges in two water properties, salinity and turbidity. These two metrics affect anchovy juveniles and larvae (and eventually its fishery) and are of concern to agriculture uses. High turbidity and low salinity have a negative effect on the nursery role while high turbidity and high salinity have detrimental effects for rice production. These two water properties are affected by the timing, frequency, volume and type of discharges and hence, subject to management. Roughly, high discharges reduce salinity posing a trade-off between agriculture and fisheries. There exists enough scientific knowledge based on historical time series and salinity and turbidity are currently monitored on real time (CSIC, 2010). For these reasons they stand out as candidate indicators.

The definition of reference points to these indicators could serve to reconcile multi-sectoral management decisions, basically visions 2 and 3 described earlier (Figure 4).

Governance

Lack of governance structures and mandates to implement EBM have been frequently invoked (Walther and Möllmann, 2014; Patrick and Link, 2015). In the previous sections the high-level goals and supranational bodies were enumerated and permanent as well as ephemeral (or event-driven) institutional arrangements were identified.

The fisheries sector was, however, not always sufficiently represented when conflict has arisen. In the last couple of years this situation has started to change. Since 2014 WWF and SOLDECOCOS have been developing an intense programme with local communities and the MPA board. This includes scoping workshops that managed to bring together fishermen, women's associations, scientists and the regional government. At the moment these meetings are very much centred on direct threats and fishing regulations within the MPA and do not address distant pressures. In particular, they haven't succeeded in attracting the agriculture sectors. This does not mean that the local communities are not aware of the impact of upstream sectoral activities on their livelihoods. Rather, they feel that they lack the political clout to enter into the process. In this sense, the development of functional organisational structures would empower and enable them to become active players. This is actually one of the development goals set by WWF and SOLDECOCOS.

The challenge for the coming years will be to bridge the gap between fisheries and agriculture by bringing these players together.

The outcome of such a dialogue should be to reach an agreement on salinity and turbidity reference points in order to inform and improve multi-sectoral management decisions.

Lack of political willingness and leadership on the part of regional authorities, who have jurisdiction over most sectoral activities, has also been identified as a problem (CSIC, 2010; Vargas and Paneque, 2015). Hence, further commitment and endorsement by the political authorities would de desirable.

Conclusions

In the last years enough scientific knowledge, data and models have been developed and could be readily used to formulate alternative ecosystem management strategies in the GoC. Stakeholder interests and agendas are well defined and a number of existing advisory boards are in place and could be easily transformed into multi-sectoral institutional arrangements in support of EBM.

The pressures and conflicts affecting this socio-ecosystem are not at a standstill, rather the same old struggle is knocking at the door one more time. The dredging project, the reopening of the mine, the active land uses, raising conservation concerns, and a fluctuating pressure from the fishing sector, depending on whether the EU-Moroccan fisheries partnership agreement is at work or not, represent some of the latent tensions. Most sectors are desperately calling for an ecosystem approach and there is capacity to make decisions cognizant of trade-offs.

Previous conflicts have revealed that lack of participation and stakeholder acceptance resulted in an expensive and time-consuming way to get nowhere. Located in one of the most deprived Spanish regions, with the highest unemployment rate in the entire EU (>30%), the GoC has a clear stake in operationalizing an ecosystem approach capable of balancing various political, social, economic and conservation interests and by doing so take advantage of Blue Growth opportunities (EC, 2014).

Acknowledgements

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Contribution to the Themed Section: '*Case studies in operationalizing ecosystem-based management*'

Food for Thought

An approach for effective stakeholder engagement as an essential component of the ecosystem approach

Jennifer Oates* and Lyndsey A. Dodds

WWF-UK, The Living Planet Centre, Rufford House, Brewery Road, Woking, Surrey GU21 4LL, UK

Corresponding author: tel: +44 (0)1483 412 343; e-mail: italjoates@wwf.org.uk

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Effective stakeholder engagement is an essential, but commonly overlooked, component of the ecosystem approach. In this article, we draw lessons from two European Union LIFE+ (LIFE is the European Union's financial instrument supporting environmental, nature conservation and climate action projects throughout the EU.) funded projects led by WWF-UK: Partnerships Involving Stakeholders in the Celtic sea EcoSystem (PISCES) and the Celtic Seas Partnership to present an approach for effective stakeholder engagement. These projects developed steps to operationalize the ecosystem approach within the context of a key piece of European legislation: the Marine Strategy Framework Directive (MSFD, 2008/56/EC).

The main goal of the MSFD is to achieve "Good Environmental Status" in Europe's waters by 2020 using an ecosystem-based approach. The ecosystem approach (often used synonymously with the ecosystem-based approach) is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. Effective engagement of stakeholders is a key component of the ecosystem approach, since they are an integral part of the process and their involvement leads to increased ownership and confidence in the outcomes, which in turn leads to better compliance with regulation and ultimately the long-term behaviour change that is needed to deliver sustainable management solutions.

The PISCES project developed a model for applying the ecosystem approach using multi-sectoral stakeholder engagement in the marine environment, which was taken forwards by the Celtic Seas Partnership to identify practical measures for the MSFD that can be implemented by stakeholders.

Based on the lessons learned from these projects, we identified an approach for involving stakeholders in the delivery of the ecosystem approach, which can be applied to other areas and contexts. The approach involves four overarching steps:

(1) Identify a relevant policy framework and the role of stakeholders in its implementation and identify or agree environmental, social, and economic objectives for the area.
(2) Create an open, neutral, cross-sectoral forum, and design an engagement process that creates a "safe" and inclusive space, and is facilitated independently.
(3) Demystify terminology and develop a shared vision or principles through an engagement process
(4) Collaboratively develop management actions that are needed to achieve objectives and implement them.

Keywords: ecosystem approach, Marine Strategy Framework Directive, stakeholder engagement

Introduction

In this article, we review our practical experiences of operationalizing the ecosystem approach in the Celtic Seas, based on the lessons learned from the implementation of two consecutive EU Life+ funded projects led by WWF-UK: Partnerships Involving Stakeholders in the Celtic sea EcoSystem (PISCES) (http://www.projectpisces.eu/) and the Celtic Seas Partnership (http://www.celticseaspartnership.eu). The two projects demonstrate the steps needed to put the ecosystem approach into practice within the context of a key piece of European marine conservation legislation: the Marine Strategy Framework Directive. Based on an analysis of the lessons learned from the application of the ecosystem approach in these projects, we draw out examples of best practice to develop an approach that could be applied in other regional seas.

The Marine Strategy Framework Directive (MSFD, Directive 2008/56/EC) was introduced in 2008 by the European Union as the environmental pillar of the Integrated Maritime Policy (Markus *et al.*, 2011). The main goal is to achieve or maintain "Good Environmental Status" in Europe's waters by 2020. "Good Environmental Status" involves protecting the marine environment, preventing its deterioration and restoring it where practical, while using marine resources sustainably. The Directive specifies that Member States should use an ecosystem-based approach to managing human activities.

The ecosystem approach (often used synonymously with the ecosystem-based approach) is defined as "a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way" (CBD SBSTTA, 2000). The Convention on Biological Diversity adopted a set of 12 principles (known as the Malawi principles, CBD SBSTTA, 2000, Figure 1) to guide implementation, which can be adapted to suit different contexts (Shepherd, 2008). The approach promotes conservation and sustainable use of resources, and rather than just focussing on a local jurisdiction, it requires countries and sectors to work together and communicate effectively. The involvement of stakeholders is a key component of the ecosystem approach, as outlined in several of the CBD Malawi principles (CBD SBSTTA, 2000, Figure 1). Stakeholders are integral to the management approach and active engagement is more likely to lead to increased ownership of the process, which in turn leads to better compliance and support of regulation and ultimately the long-term behaviour change that is needed to deliver the ecosystem approach.

ICES has developed guidance on the application of the ecosystem approach to management of human activities in the European Marine Environment (ICES, 2005). However, as evidenced by the experiences of participants at the AORA-CSA workshop "Making the ecosystem approach operational", the practical implementation of the ecosystem approach in the Atlantic Ocean presents many challenges to policy-makers, managers and stakeholders (ICES, 2016). These challenges include the integration of numerous policies and legislation, managing competing priorities from the growing number of different sea users, coordinating approaches between neighbouring countries and achieving effective stakeholder engagement. In particular, stakeholder engagement in management presents a significant challenge (Reed, 2008); indeed many efforts to implement the ecosystem approach do not actively involve stakeholders (Waylen *et al.*, 2014).

In this article, we will reflect on how two stakeholder-led projects: PISCES and the Celtic Seas Partnership have operationalized the ecosystem approach in the Celtic Seas to support the implementation of MSFD. Using lessons learned from these projects, we present an approach showing how stakeholder engagement can be carried out effectively across multiple sectors and countries; delivering this essential component of the ecosystem approach.

PISCES project

The LIFE+ PISCES project (2009–2012) brought together stakeholders from the main activities in the Celtic Sea (Figure 1) with the aim of increasing understanding of the ecosystem approach. PISCES aimed to improve policy and governance through developing guidance for effective engagement and delivery of the ecosystem approach, developed by key marine stakeholders and in close collaboration with governments in the Celtic Sea. The objectives of the project were to increase knowledge and understanding, improve cooperation among stakeholders and identify mechanisms for implementing the ecosystem approach. The project used expert facilitation to guide a target group of marine stakeholders to develop creative methodologies; test solutions to stakeholder engagement; explore their understanding of the ecosystem approach, and agree with wider stakeholders groups on what this means in the Celtic Sea. The key results from PISCES were an increase in understanding of the ecosystem approach among Celtic Sea stakeholders, a guide for implementing the ecosystem approach through the EU Marine Strategy Framework Directive (Roxburgh *et al.* 2012) and the identification of processes and techniques for multi-sector, regional engagement.

Celtic Seas Partnership project

Building on the successful PISCES project, the Celtic Seas Partnership is a 4-year LIFE+ funded project (2013–2016) led by WWF-UK. The Celtic Seas Partnership project builds on the PISCES principles, making them operational, and applying them in a wider area: the Celtic Seas MSFD sub-region which includes waters of UK, Ireland, and France (Figure 2). The Celtic Seas Partnership project's overall aim is to support the implementation of MSFD and delivery of Good Environmental Status in the Celtic Seas, by facilitating engagement between sectors and across borders to ensure the long-term future of the environment, while safeguarding people's livelihoods and the communities that have a relationship with the sea. The Celtic Seas Partnership project has engaged with over 950 marine stakeholders from 21 sectors, including policy makers, scientists, fisheries, energy, environmental NGOs, aquaculture, and shipping (Table 1). Building on the sectors identified in the PISCES project, sector categories were further refined in the Celtic Seas Partnership to take account of the larger geographical area. The Celtic Seas Partnership project has built on the foundations of the PISCES project, taking forwards the PISCES principles and facilitating their application by stakeholders to identify practical measures for the MSFD that they can implement using the ecosystem approach.

Our engagement approach

Based on the lessons learned from the PISCES and Celtic Seas Partnership projects, we have identified an approach for involving stakeholders in the delivery of the ecosystem approach consisting of four overarching steps.

Step 1: identify relevant policy framework and the role of stakeholders in its implementation

Identify relevant policy context

The process of applying the ecosystem approach to a specific policy or legal framework allows for more practical and tangible recommendations to be developed. We decided to focus the PISCES and Celtic Seas Partnerships projects on implementing the ecosystem approach in the context of the MSFD. This was because the Directive includes a requirement to work with neighbouring countries on a regional or sub-regional scale and a requirement to use the ecosystem-based approach; a requirement not included in domestic marine legislation in the UK. It is also an overarching framework directive that sets out environmental objectives to be applied across all the sea area, while allowing for sustainable use, and is closely linked to other key policies including the Common Fisheries Policy and the Water Framework Directive.

Both projects were framed around the relevant parts of the MSFD. During PISCES, the MSFD was in the early stages of implementation so the project facilitated stakeholders to identify where and how they could have the most input to the different stages of the MSFD cycle (Figure 3). At the time of the Celtic Seas Partnership, the MSFD required governments to develop "programmes of measures" to help achieve Good Environmental Status. Therefore, following guidance from government representatives, the project focused on gathering evidence and information from stakeholders to feed directly into and support the government measures development processes.

By making engagement policy relevant, stakeholders can clearly see a role for their input and should be able to see their input being taken into account. Equally governments and policy makers are open to input and suggestions that can feed in directly to the implementation process. Interest from governments then further incentivises involvement from stakeholders.

Principle 1: The objectives of management of land, water and living resources are a matter of societal choices.

Principle 2: Management should be decentralized to the lowest appropriate level.

Principle 3: Ecosystem managers should consider the effects (actual or potential) of their activities on adjacent and other ecosystems.

Principle 4: Recognizing potential gains from management, there is usually a need to understand and manage the ecosystem in an economic context. Any such ecosystem-management programme should:

Principle 5: Conservation of ecosystem structure and functioning, in order to maintain ecosystem services, should be a priority target of the ecosystem approach.

Principle 6: Ecosystem must be managed within the limits of their functioning.

Principle 7: The ecosystem approach should be undertaken at the appropriate spatial and temporal scales.

Principle 8: Recognizing the varying temporal scales and lag-effects that characterize ecosystem processes, objectives for ecosystem management should be set for the long term.

Principle 9: Management must recognize the change is inevitable.

Principle 10: The ecosystem approach should seek the appropriate balance between, and integration of, conservation and use of biological diversity.

Principle 11: The ecosystem approach should consider all forms of relevant information, including scientific and indigenous and local knowledge, innovations and practices.

Principle 12: The ecosystem approach should involve all relevant sectors of society and scientific disciplines.

Figure 1. The Malawi ecosystem approach principles.

Apply the ecosystem approach principles to the policy context in order to identify the role of stakeholders

The PISCES guide uses a set of agreed ecosystem approach principles (Figure 4) to identify specific roles that stakeholders can play in the different stages of MSFD implementation. For example, stakeholders can provide and collect data; identify and evaluate measures; support monitoring and compliance; and evaluate marine strategies. Stakeholders have a role in the implementation of voluntary measures to improve the sustainability of their own activities, and can encourage others to do the same. Implementing voluntary measures may help to reduce the regulatory burden and help meet policy targets. It also increasingly makes commercial sense as sustainability becomes more important to shareholders and consumers.

Step 2: create an open, neutral, cross-sectoral forum, and design an engagement process

Establish a neutral forum

PISCES and the Celtic Seas Partnership were the first to achieve effective engagement from stakeholders across multiple marine sectors at this scale. In order to do this, it was necessary to create an open, neutral forum that involved careful communication with stakeholders to avoid any perception of bias. Both projects adopted a neutral "brand" that distinguished the project from

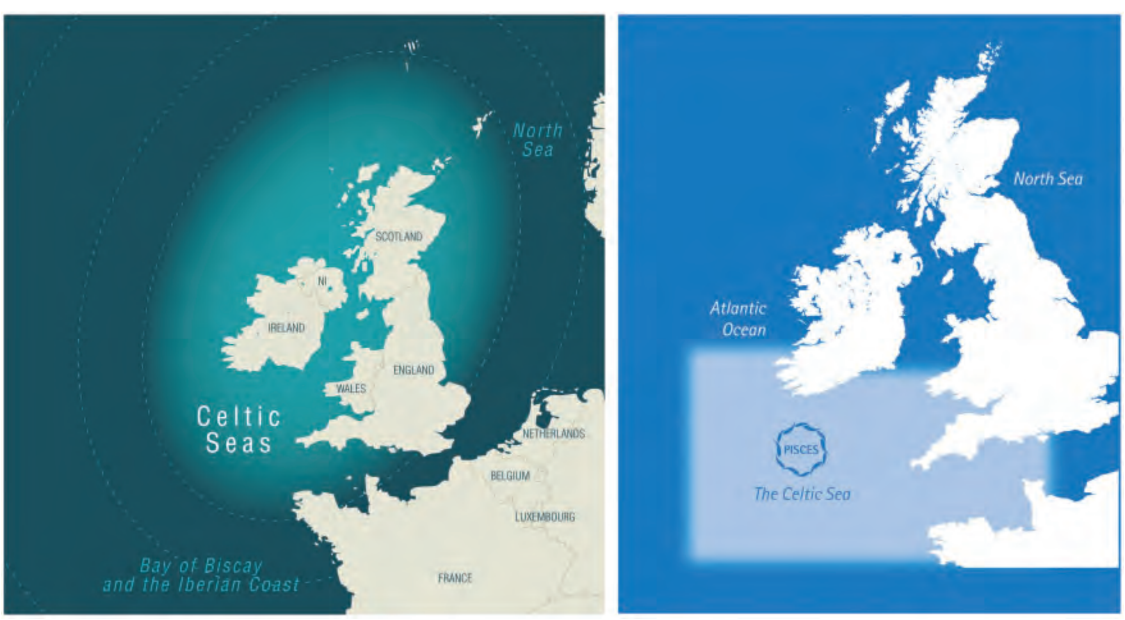

Figure 2. Map of Celtic Seas and PISCES areas.

Table 1. Stakeholder sectors directly involved in PISCES and Celtic Seas Partnership

Sectors directly involved in development of PISCES guide	**Sectors engaged with in Celtic Seas Partnership**
Academic	Aquaculture
Coastal tourism/recreational industries (incl angling)	Cabling
Environmental statutory agencies	Chemical industry
Fisheries	Coastal Group or Partnership
Government	Consultants
Mariculture	Energy – other
Marine Aggregates	Fisheries
Marine renewable energy	Government
Offshore operators including oil, gas and undersea infrastructure	Leisure and Tourism
Ports	Local Government
Shipping	Military
	NGO/Conservation Group
	Nuclear industry
	Oil and Gas
	Ports
	Recreational angling
	Renewable Energy
	Research Institute/Academic
	Shipping
	Statutory Body/Agency
	Water industry

any one partner to create a sense of shared ownership. By taking an open, neutral approach, this helped deliver participation from a broad range of stakeholders and facilitated discussions between a range of sectors.

Despite this approach, there was varying success in engaging the fisheries sector in the PISCES project. This is likely to be due to the perception that the MSFD is less directly relevant to fisheries than the Common Fisheries Policy and has a clear emphasis on environmental objectives, as well as tensions in relationships between fisheries and environmental NGOs. The Celtic Seas Partnership attempted to tackle this issue by running a pilot mediation process to improve relationships and build a shared understanding among fisheries, eNGOs, and government. In addition, by focusing on particular measures under the MSFD that are directly relevant to fisheries stakeholders, there was an increased motivation to become involved in those project activities.

For all sectors, it is important to tailor outputs and activities to the needs of different stakeholders as well as ensuring that there is a willingness to adapt engagement strategies and approaches to changing contexts and developing relationships.

Develop a well-resourced stakeholder engagement strategy

Effective engagement with stakeholders involves participation and empowerment rather than simply consultation. In order to achieve this, in the PISCES and Celtic Seas Partnership projects,

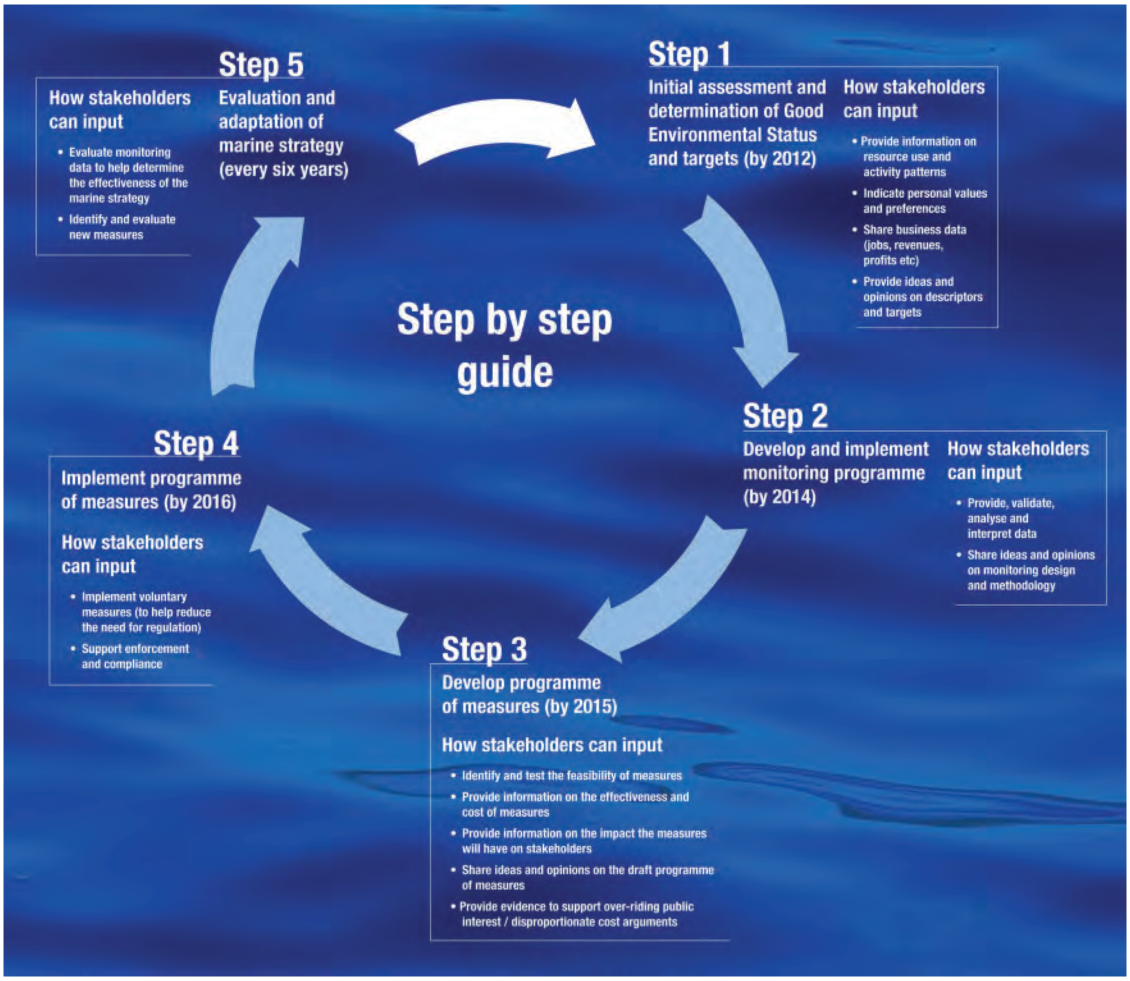

Figure 3. Role of stakeholders in MSFD.

long-term engagement strategies were developed to ensure continuous engagement between events and workshops to maintain commitment.

It became clear that stakeholder engagement needs to be well resourced. The projects were unique in terms of the geographical scale of engagement, which involved engaging with stakeholders from several countries. This scale of engagement was essential for being able to consider local issues as well as identify key transboundary issues for discussion. The open and inclusive engagement approach in PISCES to collaboratively engaging stakeholders in developing the guide proved to be incredibly resource intensive. At each stage of development, we wanted to engage as many people as possible in as much detail as possible as well as then share emerging outputs for further discussion. On top of this, relationships needed to be maintained with the entire stakeholder group to ensure continuing commitment as well as a need for communication with wider stakeholders. In increasing the scale of the approach in the Celtic Seas Partnership project, we recognized the resource implications and included dedicated Stakeholder Engagement Officers in each of the six project countries. We also provided financial support to enable stakeholders to travel to workshops in other countries, and used innovative online tools for allowing stakeholders in different locations to work collaboratively in task groups.

Ensure engagement with governments

Securing commitments from governments to engage in the process was critical to success in both projects. This commitment adds weight to the project outcomes, helps to develop the most useful focus of project outputs, and also acts as an incentive for other sectors to engage. In the Celtic Seas Partnership project, it was essential to build a strong relationship with the relevant government representatives right from the start, and then ensure a regular dialogue so that the projects could be adapted to fit in with policy priorities and timelines in the different countries. In order to facilitate this, we set up an "Observer Board" for the project consisting of representatives from each of the Celtic Seas governments, the EC and OSPAR. Regular meetings and teleconferences were held to discuss project activities in the wider policy context of the Celtic Seas countries, which enabled the project team to tailor project activities to suit the needs of the different countries.

At the start of the Celtic Seas Partnership project, there was some confusion among stakeholders regarding how the project would complement government stakeholder consultation around the MSFD, which led to an initial reluctance from stakeholders to engage in the project. Therefore, in subsequent communications with stakeholders, we made sure that stakeholders were aware of the government processes and where there would be opportunities to provide input into MSFD consultations. We also ensured that the role of the project and the purpose of the project activities were clear, so that stakeholders understood that we were supporting policy implementation rather than making policy. We also explained the benefits to different stakeholder groups of being involved in the projects.

Step 3: demystify terminology and develop a shared vision or principles through an engagement process

Demystify terminology and build understanding

In order to empower stakeholders so that they can become involved in the implementation of the ecosystem approach as

The PISCES principles reflect many of the same elements as the Malawi Principles but with a more explicit emphasis on stakeholder involvement (P1) and the need to connect strategies and management across multiple scales (P8). The final agreed principles were:

Principle 1	**Stakeholder role:** stakeholders should adopt an active and committed role to achieve the common goal of the ecosystem approach; stakeholders should be involved in all aspects of management leading to a shared understanding of objectives.
Principle 2:	**Balance:** there should be a suitable balance between conservation and the sustainable use of resources in the interests of the health of the whole ecosystem.
Principle 3:	**Evidence:** an evidence-based system should be used to integrate social, environmental and economic interests.
Principle 4:	**Adaptive:** management should use an iterative and flexible approach.
Principle 5:	**Timescales:** management should be set for the long term with short- and medium-term objectives and milestones and should enable involvement of future stakeholders.
Principle 6:	**Economic sensitivity:** involvement in implementing the ecosystem approach should not create an economic disadvantage but should promote responsible and sustainable behaviour.
Principle 7:	**Subsidiarity:** management should be undertaken by the smallest, lowest, or least-centralised competent authority.
Principle 8:	**Connecting international through to local:** local and sectoral strategies, plans and policies should be harmonised and priorities established to reflect national and international goals and objectives for conservation and sustainable use.
Principle 9:	**Review and monitoring:** an effective and targeted performance monitoring and review regime should be used to inform management.
Principle 10:	**Adjacent impacts:** consideration should be given to how events or actions in the Celtic Sea can influence or be influenced by events or actions on the land, in the air or in different parts of the ocean.
Principle 11:	**Involve and inform:** management should involve and inform all relevant sectors of society and scientific disciplines.

Figure 4. PISCES ecosystem approach principles.

part of a policy framework, it is important to design activities focussed on building understanding of the technical terminology. The importance of understanding the Malawi principles (Figure 1, CBD SBSTTA, 2000) in order to properly implement them is emphasised by Waylen *et al.* (2014).

In order to develop understanding of the ecosystem approach with stakeholders we found that it needed to be done in a practical rather than theoretical way. This was identified by initially taking an unsuccessful approach in the PISCES project. At the first PISCES workshop, we invited a number of academic experts to explain and debate the concepts of the ecosystem approach, which although interesting, was not what was needed for a practical group of stakeholders who were giving up their time to attend our event. In order to address this subsequently, we found ways to communicate the ecosystem approach in more practical terms, for example by inviting a fisherman from the west coast of the USA involved in an ecosystem-based management programme to give his perspectives. In addition, by linking the ecosystem approach to the MSFD, stakeholders could get a sense of the practical applications of it.

In expanding our engagement through the Celtic Seas Partnership project, we realised that there was not a common understanding among all stakeholders of the components of the ecosystem approach and of the MSFD and how these related to their activities. Therefore, at our first multi-national workshop, we designed activities to introduce stakeholders to the ecosystem approach and different themes covered in MSFD (descriptors) and gauge their interest and ability to influence these. The project has also developed various products which support stakeholders to implement the MSFD using the ecosystem approach. These include an online tutorial for stakeholders explaining MSFD using an animation and interviews with key policy experts and a report on the future trends of marine sectors in the Celtic Seas and their potential impacts on the environment and economy.

Develop shared principles

Experience in PISCES showed that the process of developing shared principles leads to common understanding and greater cohesion between stakeholders as well as an increased willingness to then identify how to put the principles into practice. This was achieved by developing PISCES ecosystem approach principles (see Figure 4), through an iterative and collaborative process. The outputs of a session at the first PISCES workshop held in Cardiff in May 2010 on the "benefits and challenges" of the ecosystem approach were collated and compared with the CBD Malawi principles to create an initial draft list or "strawman" of principles. At the next workshop in Cork in November 2010, the stakeholders were asked to consider and discuss the draft principles in small groups and then collectively share their thoughts on the suitability of the principles. A number of amendments were suggested and these were incorporated into a revised draft that was discussed in the second day of the workshop. A further iteration of the principles was developed remotely in collaboration with stakeholders who attended the workshop as well as others who had been able to attend until agreement was reached by all.

Step 4: collaboratively develop management actions that are needed to achieve objectives and implement them

Identify priority gaps in current management

In order to focus effort on adding maximum value, it is important to identify and target priority gaps in existing management.

In the Celtic Seas Partnership, we used a combination of stakeholder workshops, online surveys, and consultation with the Observer Board to develop ideas for management measures and identify priority descriptors where new measures were needed based on stakeholder interests and current gaps or weaknesses. We evaluated ideas for measures developed by stakeholders to determine which could be taken forwards as stakeholder initiatives (in "task groups") and which could be submitted as recommendations to government as part of the consultations on Programmes of Measures.

Facilitate development of stakeholder-led solutions and provide tools for resolving conflict

When developing new sustainable management solutions, it is essential that these are led by stakeholders themselves since they are more likely to feel personal investment, ownership, and buy-into the process, resulting in more effective behaviour change and compliance. Over the course of the Celtic Seas Partnership project, over 15 stakeholder workshops were held at national and multi-national levels at key points throughout the MSFD implementation process, providing a unique forum for coordination and sharing of experience across sectors and countries at a Celtic Seas scale. At these workshops, stakeholders collaboratively developed ideas for new management measures to contribute to MSFD.

Following this, we established "task groups" to further refine some of the management measures that will have the greatest impact and those that stakeholders have the power to implement. These groups were formed of stakeholders from industry, government, environmental non-governmental organisations, and academic and research institutions from across the Celtic Seas countries. In the task groups, stakeholders have worked together to develop detailed action plans for specific initiatives that can be taken forwards by stakeholders to promote Good Environmental Status at a Celtic Seas scale. These include a scheme to involve the fishing industry in collecting monitoring data, developing a Celtic Seas scale biosecurity protocol for non-indigenous species, and designing a pilot project to develop resources for use in schools to increase understanding and action on the problem of marine litter. When these groups were initially set up, it was a challenge to bring a diverse range of stakeholders with different priorities together to work collectively on a single focussed initiative. Therefore, we learned that good facilitation was needed, and it was important to clearly communicate decisions to focus on certain issues to the groups in order to avoid disengagement from those that felt that the chosen issues were not as important to them individually.

Where real or perceived conflicts exist, these can present barriers to implementing the ecosystem approach, which creates a need for providing stakeholders with the necessary tools for resolving these conflicts. We also developed a series of best practice guidelines based on real-life case studies which can be used by stakeholders to resolve challenges associated with transboundary marine governance, co-location of marine renewables and marine conflicts.

Conclusion

The active engagement of stakeholders is a key component of the ecosystem approach and is the essential foundation for its practical delivery (CBD SBSTTA, 2000; Waylen *et al*., 2014). Experiences from PISCES and the Celtic Seas Partnership demonstrate that effective stakeholder engagement is critical for delivery of the ecosystem approach. Through engagement processes, relationships are built, understanding of policy processes and the goals and objectives of other sectors are increased and sustainable solutions to management practices can be identified and implemented. In this paper, we present an approach to effective stakeholder engagement based on lessons learned from two multi-stakeholder, multi-national projects. This approach could be applied to other MSFD sub-regions in Europe as well as to other place-based management in Europe and beyond. There is relevance to other policy frameworks including marine spatial planning.

As evidenced here, there is a need for greater collaboration and communication between stakeholders and between stakeholders and government, at national and transboundary levels. Multi-sector, regional stakeholder forums should be established as a mechanism for engagement in policy implementation and sharing knowledge and experience across sectors and borders to ensure delivery of the ecosystem approach. Forums can enable stakeholders to explore interactions and conflicts, understand different perspectives and gain knowledge and information about other sectors' activities. Such forums need to be neutral, representative, adequately funded, and formally recognised.

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Contribution to the Themed Section: '*Case studies in operationalizing ecosystem-based management*'

Food for Thought

Implementing "the IEA": using integrated ecosystem assessment frameworks, programs, and applications in support of operationalizing ecosystem-based management

Chris J. Harvey[1], Christopher R. Kelble[2,*], and Franklin B. Schwing[3]

[1]*Conservation Biology Division, Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 2725 Montlake Blvd E, Seattle, WA 98112, USA*
[2]*Ocean Chemistry and Ecosystems Division, Atlantic Oceanographic and Meteorological Laboratory, Office of Oceanic and Atmospheric Research, National Oceanic and Atmospheric Administration, 4301 Rickenbacker Causeway, Miami, FL 33149, USA*
[3]*Science Information Division, Office of Science and Technology, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 1315 East-West Highway, Silver Spring, MD 20910, USA*

**Corresponding author: E-mail: Chris.Kelble@noaa.gov*

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The Integrated Ecosystem Assessment (IEA) approach was designed to assimilate scientific knowledge in the ideal format for providing advice to inform marine Ecosystem-Based Management (EBM). As such, IEAs were envisioned as the cornerstone integrated science product for the US National Oceanic and Atmospheric Administration (NOAA) that would maximize efficiencies and synergies across the agency's ecosystem science efforts. This led to the development of a NOAA IEA Program that would oversee regional implementation of the national IEA framework. As implementation proceeded, uptake by management entities was slower than anticipated, in part because EBM was not quickly embraced and applied to achieve management objectives. This slow movement to EBM in conjunction with the need to develop scientific analyses and methods to properly implement IEA resulted in the IEA process being viewed as its own endpoint. This commonly led to referring to "the IEA" when variously discussing the IEA framework, program, products, and process. Now that IEA and EBM are maturing, we need to be specific with what we are referring to when discussing IEAs, in order to develop reasonable expectations for applying IEA tools. We also now recognize the need to implement multiple IEA processes at varying geographic and complexity scales within an ecosystem to effectively meet the scientific requirements for operational EBM rather than viewing an IEA application as a single regional science product.

Keywords: decision support tools, ecosystem-based management, fisheries, frameworks, integrated ecosystem assessments, marine spatial planning.

Introduction

Implementing ecosystem-based approaches to managing marine resources is a priority throughout the world, from local and regional scales to large marine ecosystems (Arkema *et al.*, 2006; Leslie and McLeod, 2007; Lester *et al.*, 2010). While the goals and objectives of marine ecosystem-based management (EBM) are wide-ranging, an essential principle at the core of EBM is that individual ecosystem components (e.g. species, habitats, processes, activities, services, values, human well-being) are intrinsically linked to other components. Therefore, effective management activities should span beyond individual components and consider the meaningful linkages to the rest of the ecosystem. This is especially true in regions where there is potential for management trade-offs, such as where a particular management policy has influence over activities that affect species and habitats far beyond the focal species (Fogarty and Murawski, 1998; Mumby, 2006; McClanahan *et al.*, 2011), or where the activities of multiple human sectors have high overlap in time and space (Halpern *et al.*, 2008; White *et al.*, 2012; Andrews *et al.*, 2015). Similarly, an EBM approach is likely more effective than traditional single-resource or single-sector management strategies in cases where global change or human activities are pushing ecosystems and resource needs toward conditions of greater uncertainty relative to our current understanding, or where multiple interacting pressures result in cumulative impacts upon ecosystem components (Olsson *et al.*, 2008; Flores *et al.*, 2012; Niiranen *et al.*, 2013).

Amassing and synthesizing the information needed to provide effective scientific guidance for marine EBM is a huge and difficult undertaking (Sainsbury *et al.*, 2000; Borja *et al.*, 2006; Atkins *et al.*, 2011; Portman, 2011). In the US, one major effort has been the development of the Integrated Ecosystem Assessment (IEA) program within the National Oceanic and Atmospheric Administration (NOAA), the agency most responsible for research, management and conservation of oceans in US waters; similar efforts are well underway throughout the world (Foley *et al.*, 2013; Walther and Möllmann, 2014). The NOAA IEA program supports and coordinates national and regional implementation of the IEA process in support of marine EBM. This iterative process, which is thoroughly outlined elsewhere (Levin *et al.*, 2008, 2009; Foley *et al.*, 2013), involves defining ecosystem goals, assessing the status of ecosystem indicators and attributes, analysing risk, and evaluating the likely outcomes and trade-offs among alternative management strategies (Figure 1). The IEA process is being implemented in five regions of US marine waters to address a range of EBM objectives relevant to many resources, jurisdictions, and stakeholders (Samhouri *et al.*, 2014). In particular, NOAA scientists in each region are applying the IEA process to EBM questions related to climate change, human well-being, management trade-offs, cumulative impacts, and ecosystem thresholds.

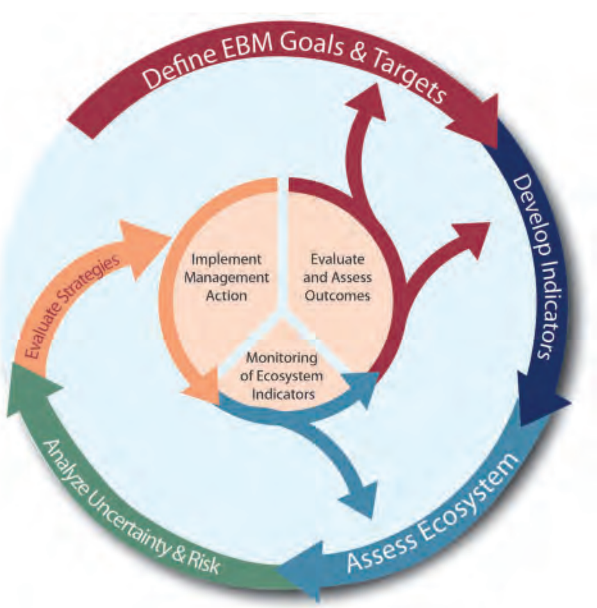

Figure 1. The Integrated Ecosystem Assessment (IEA) loop, outlining the general steps that an IEA iteratively follows to meet the ecosystem-based management (EBM) goals defined at the start of each iteration. From Samhouri *et al.* (2014).

After roughly 7 years of funding for the NOAA National IEA program, we have learned much about the development and implementation of IEA science in support of marine EBM in the US (Foley *et al.*, 2013; Levin *et al.*, 2014; Samhouri *et al.*, 2014). Moreover, in each region, IEA scientists have developed strong working relationships with different local, state and federal resource management entities. As these relationships have grown, we have observed an emerging tendency for scientists, managers, policy makers, stakeholders, and other partners to refer to "the IEA," both verbally and in writing, regardless of whether they are talking about the National or regional IEA programs, or the established IEA methodological framework, or a comprehensive ecosystem status report produced by a regional IEA program, or a specific application of IEA methods. In fact, the authors of this paper often reflexively say or write "the IEA" in many of these contexts. However, we believe that the practice of integrated ecosystem assessment has matured to a point that referring to all of its aspects (framework, program, process, product, and tool) as "*the* IEA" is problematic, and not merely in a semantic sense. Although the different aspects of IEA are clearly related, they are not interchangeable, and referring to them or thinking about them in that manner could be misleading in a way that slows EBM implementation.

In this paper, we review the development and evolution of the NOAA IEA program to illustrate the difference and significance of "*the* IEA" vs. "*an* IEA." It is our hope that elucidating the differences among these terms will help to clarify reasonable expectations for the overall IEA approach, which can only improve its scientific value and the efficiency with which it supports marine EBM implementation. We anticipate that some of our experiences will be useful to similar IEA and EBM efforts in other parts of the world. We will begin by exploring how the history of IEAs in NOAA led to various perceptions of "*the IEA*." This view needs to evolve to more clearly articulate the roles and uses of the IEA framework, program, products, and process. In closing we will propose the need to evolve our thinking to view IEA as a process for implementing the IEA framework at multiple geographic and complexity scales, in order to provide scientific advice necessary to operationalize EBM.

EBM and IEAs in NOAA

NOAA's missions and mandates have focused increasingly on ecosystem approaches to protect, restore, and manage the use of coastal, ocean, and Great Lakes resources and services (NOAA, 2004; Patrick and Link, 2015). More than 90 separate US Federal legislative and executive mandates give NOAA implicit or explicit EBM stewardship authorities (McFadden and Barnes, 2009), and provide opportunities for IEA science to support the management of ocean and coastal ecosystems and fisheries. The National Environmental Policy Act (NEPA; 42 U.S.C. §4321) of 1969 requires Federal agencies to evaluate cumulative impacts when making permitting decisions, a concept essential to EBM. The Magnuson-Stevens Fishery Conservation and Management Act (MSA; 16 U.S.C. §1801) of 1976 tasked the NOAA National Marine Fisheries Service with managing marine fishery resources in the US exclusive economic zone. MSA updates in 1996 and 2007, respectively, added substantial ecosystem-based fisheries management (EBFM) requirements, and directed NOAA to engage regional Fishery Management Councils (FMCs) in regional studies and assessments of ecosystem considerations related to fisheries management (deReynier, 2014). Since the publication of a landmark EBFM advisory report (Ecosystem Principles Advisory Panel, 1999), many FMCs began developing Fishery Ecosystem Plans (FEPs) (deReynier, 2012; Dolan *et al*., 2016).

In 2004, an external Ecosystem Task Team (eETT) established by NOAA recommended regional IEAs to be the "cornerstone for NOAA to maximize efficiencies and synergies in providing a single integrated science product" (Fluharty *et al*., 2006). To adopt the more holistic, science-based ecosystem focus recommended by the eETT, NOAA identified IEAs as an approach to address agency-wide science and management problems, and then created an IEA national program and framework in 2008 (Figure 1) (Levin *et al*., 2008, 2009). Five regional IEA programs were implemented (Figure 2) to provide science support for marine EBM (NOAA, 2007), thus connecting the national programmatic framework to the regional scientific process. A subtle but important element of the NOAA IEA framework was to connect science to management by firmly staking the entire approach on ecosystem management objectives, from the initial scoping of EBM goals and targets to the final step of evaluating alternate management strategies (Levin *et al*., 2008, 2009). The EBM context became more explicit as the NOAA IEA framework evolved (Samhouri *et al*., 2014).

A number of national reviews (e.g. US Commission on Ocean Policy, Pew Oceans Commission, Joint Ocean Commission Initiative) in the early 2000s highlighted the importance of incorporating ecosystem principles in ocean and coastal resource management, but did not lay out a process for developing IEAs or implementing EBM. The US National Ocean Policy (NOP; US Executive Order 13547), signed in 2009, established EBM as a foundation for achieving domestic marine economic, sustainability, and conservation goals. The NOP also established Regional Planning Bodies (RPBs) and charged them with developing regional ocean plans as a mechanism to establish spatial EBM management measures. Thus, the regional ocean planning collaboration and fisheries management partnerships with FMCs were natural fits in the formative stage of the IEA approach at the

Figure 2. Map of the five active regions in the NOAA IEA program. (Credit: Avi Litwack).

NOAA and Federal levels. However, the NOP in general, and marine planning in particular, have not been implemented as quickly as originally hoped. This meant that the growing regional IEA programs had to seek out other management priorities and partners in the interest of EBM beyond the fisheries sector. Regional IEA programs have evolved from full ecosystem assessments to addressing a limited set of management questions as they have matured.

Further evolution and "the IEA" vs. "an IEA"

As NOAA IEA efforts continued nationally and regionally, the idealized vision of IEA (equal parts process, product, framework, and tool) that was formulated in the planning stages began to evolve into realized versions of IEA as implemented in the real world. The evolution was necessitated by factors like slow buy-in from management partners, limited availability of funds and staff time, state of the science on integrated socioecological systems, tool development, and emerging priorities within and across regions (e.g. emphasis on climate variability and the need to better understand the role of humans in ecosystem functioning). In some respects, this process of evolution has made IEA more difficult to define (Dickey-Collas, 2014), and it has gradually become clear that IEA practitioners and end-users often define IEA in fundamentally different ways. Below, we outline some of these key differences and their ramifications, focusing on the aforementioned context of referring to "the IEA" as opposed to "an IEA" or, simply, "IEA."

The IEA framework and process

A framework is a set of guiding principles for a system or concept. It serves as a common blueprint or template for implementing a process to achieve an objective. As outlined below, we view the IEA framework and the IEA process as the essence of integrated ecosystem assessment; however, neither the framework nor the process stands alone as "*the* IEA," an end unto itself. The framework and the process guide development of products that serve the true end: informed ecosystem-based management.

The IEA framework adopted by NOAA consists of five iterative steps, plus monitoring and evaluation after a management measure has been implemented (Figure 1). The IEA framework was originally proposed by Levin *et al.* (2008), and has since been modified to account for lessons learned over the past 7 years (Samhouri *et al*., 2014). The framework has been discussed in detail elsewhere (Levin *et al*., 2008, 2009; Foley *et al*., 2013; Levin *et al*., 2014). What is germane to this discussion is that the IEA framework provides a generalized structure or methodology to develop science advice for EBM. Referring to "the IEA framework" (or "the IEA loop") is appropriate because doing so is a specific reference to the underlying structure of an IEA, specifically the steps summarized in Figure 1.

An IEA process is the series of scientific actions taken to complete all or some of the steps in the IEA framework. Specifying "the IEA framework" or "an IEA process" underscores the practical truth that integrated ecosystem assessment is first and foremost a scientific process designed to implement the IEA framework. The process is the formal practice of analysis and synthesis designed to complete the steps in the IEA framework and maximize utility for EBM (Levin *et al*., 2009; Dickey-Collas, 2014). This process has been very carefully conceived over many years by a number of researchers (Levin *et al*., 2008, 2009;

Fletcher *et al.*, 2014; Levin *et al.*, 2014; Samhouri *et al.*, 2014), drawing important elements from other scientific frameworks and processes such as decision analysis (Keeney and Raiffa, 1993), the Millennium Ecosystem Assessment (2005), ecosystem indicator selection (Rice and Rochet, 2005; Kershner *et al.*, 2011), management strategy evaluation (Sainsbury *et al.*, 2000; Smith *et al.*, 2007), and DPSIR (driver-pressure-state-impact-response; Borja *et al.*, 2006). The IEA framework is completely portable and transferrable to any ecosystem management objective or issue; thus, the process and framework of IEA is more far-reaching than any one IEA application, program, or network.

In retrospect, the NOAA IEA framework was initially developed and implemented to focus upon EBM science support at the scale of large marine ecosystems (LMEs). That implementation was hampered by the slow progress of formal regional governance or planning bodies, and by the lack of US Federal legislation or authority explicitly calling for EBM. Moreover, while several of the Fisheries Management Councils have embraced ecosystem considerations, progress toward integrating IEA science support and EBM principles into federal fisheries management has been slow. Thus, for the past 7 years, the IEA framework has largely been applied to provide scientific advice despite the lack of LME-scale EBM planning or management bodies capable of taking up this advice and using it. In that time, the IEA framework and associated scientific tools (e.g. methodologies for indicator screening, risk assessment, and management strategy evaluation) continued to evolve, and received more attention than the management processes they were intended to inform. This may have led to the framework being viewed as "the IEA"—an end unto itself, which is absolutely inappropriate. The IEA framework is one of many science support tools being applied toward the more important endpoint of informed EBM.

The IEA program (National or regional)

The evolution of the NOAA IEA approach and the uptake of IEA products have been shepherded by an IEA program. The regional programs have overseen a period of remarkable productivity, and have also represented IEA efforts within and beyond the agency. As the coordinator and public face of the NOAA IEA approach, the program is often referred to as "the IEA," but we discourage that, even as a form of conversational shorthand, because the framework, process, and products are ultimately more important than the institutional structure; also, the IEA approach can be implemented by anyone, and is not the exclusive province of specific agency programs.

The NOAA IEA Program presently consists of a National program (a headquarters-based office, supported by a steering committee with regional and at-large members) and five active regional programs (Figure 2). The National program and steering committee provide guidance on priorities, funding, and agency-level initiatives; oversee special projects and working groups; and ensure coordination and communication among the regions and across different agency line offices. The regional programs develop work plans to implement iterations of the IEA process, and foster collaborations with research partners and regional management entities. Management partners sit within and external of NOAA, and have included RPBs, FMCs, the National Park Service, states, tribal governments, and place-based management entities such as National Marine Sanctuaries.

At present, there is clearly utility in referring to "the IEA program," be it the overarching National program or one of the five regional programs, because these programs serve as bodies that are guiding the maturation of the IEA approach, developing partnerships with management bodies (whose objectives are key to the first and last steps of the IEA framework, Figure 1), and coordinating NOAA IEA efforts with other agency efforts, such as formulating strategies for conducting effective climate change science (Link *et al.*, 2015) or science in support of EBFM (National Marine Fisheries Service, 2016). It is foreseeable that the IEA approach will mature to a more ubiquitous framework that is applied throughout the agency, which would diminish the need for centralized national or regional programs, but we are not at that point presently. Referring to "the IEA program" also puts a clear distinction between the organizational side of the effort and any of its science products, which are by definition iterative products in support of continuously evolving management challenges.

It is important, however, that we avoid referring to the National or regional IEA programs as "the IEA," because doing so emphasizes program over process, and as we noted above ("The IEA framework"), the process—the framework, the practice, the implementation of science support into EBM—is the key element. Similarly, calling a program "the IEA" emphasizes the program over its products. With the slow transition to marine EBM, uptake of IEA products by management partners has not been as swift as hoped. Thus, some regional IEA programs put considerable effort in their formative years into conducting integrative science and generating publications as a means of establishing scientific credibility for their program. While these efforts were important in cementing the trust of management partners and establishing the IEA framework as a scientifically valid process, they may have skewed early products from the NOAA IEA program toward scientific publications over decision-support products for management. For example, the California Current IEA program, co-led by the NOAA Northwest and Southwest Fisheries Science Centres, has generated over 100 peer-reviewed papers and scientific reports since its inception, but in the same time has contributed only $\sim$10 decision-support products, none of which would constitute a complete iteration of the IEA loop (Figure 1). The desire to establish programmatic credibility also led some IEA programs to "study everything," expending extreme effort to assess the entire ecosystem in hopes of demonstrating management relevance to prospective management partners. Such effort is clear in the extensive screening of ecosystem indicators and development of analytical methods in the first three full reports of the California Current IEA program (Levin and Schwing, 2011; Levin *et al.*, 2013; Harvey *et al.*, 2014), and also in the initial efforts to identify patterns of ecosystem organization in the Gulf of Mexico (Karnauskas *et al.*, 2015). These efforts have profound scientific value, and their importance should in no way be discounted. In fact, they may even be necessary in the evolution of an IEA program because they provide essential context in which to assess the status of marine resources and services. However, greater long-term management value may ultimately be found in focused IEA products that are applied to serve the specific EBM needs of our partners. Regional NOAA IEA programs are moving in this direction through greater emphasis on the initial IEA step of teaming with managers, policymakers and stakeholders to define EBM goals and targets (Figure 1). Sustained output of applicable science products is far more important in the long run than maintaining a program as a cog in a federal agency.

Referring to a program as "the IEA" also feeds a perception among other scientists, both within and outside of NOAA, that integrative science in support of EBM is the province of an exclusive group of anointed people and funding streams. This perception is harmful in that it creates artificial division between research efforts, which is in direct opposition to the goal of conducting integrative, transdisciplinary science, and a broader concept that federal research has some direct or indirect management or operational application. To meet the ever-expanding demand for science support for EBM, NOAA and other agencies will have to rely on all programs, with the IEA program and products just one option to support decision making. A wealth of excellent ecosystem research is being done by research teams that are not affiliated with IEA programs, and their work can and should be integrated into the general IEA framework when possible and practical. Moreover, their work should not be discounted by potential end-users based on the perception that it did not originate from an imagined EBM ivory tower.

IEA applications and products

During its formative stages, IEA was described as a cornerstone integrated science product (Fuharty *et al.*, 2006). While an IEA effort can potentially be a product unto itself, it should not be viewed as the endpoint, as it is undertaken to improve ecosystem management. Defining IEA as a product may lead to the unintended assumption that a regional IEA program will produce a single product, "*the* IEA," and the endeavour will then be complete. We have learned after 7 years of employing IEA processes to implement the IEA framework that a number of decision-support products useful to ecosystem management are produced during each step in the framework (Fletcher *et al.*, 2014; Samhouri *et al.*, 2014).

Programs apply the IEA framework and methods to address ecosystem-scale questions, either of a broad contextual nature or of a specific management-related nature. These applications lead to numerous products, ranging from research tools to publications to specific recommendations to managers and policy-makers. As the NOAA IEA framework has evolved and the regional IEA programs have matured, we have developed better intuition of what is feasible to achieve given our knowledge, resources, and the complexities of real-world EBM faced by our management partners. One view that has emerged is that the IEA approach will be most effective when multiple IEA applications are pursued within a single ecosystem, rather than a single integrative assessment of the entire ecosystem at once (i.e. the impractical "study everything" approach alluded to in the previous section). In this view, the IEA process can inform EBM both contextually and specifically. The integration of data and disciplines helps provide the status and trends of the overall ecosystem, which provides context for IEA applications and products in support of specific EBM objectives.

In essence, this is the realization of the long-held concept that the IEA approach is scalable and tractable in complexity (e.g. management objectives, human use sectors, and scientific disciplines) and geography (e.g. national, regional, and place-based). While this was stated in the initial call for the use of IEAs and in many foundational papers on IEA, it was never clearly articulated how this scaling would occur within the IEA framework. We have learned that the best method for this scaling is to not view the IEA framework as an end unto itself, but rather as a methodology to be applied and tailored to specific decision-making processes. Scoping with stakeholders and decision-makers at the onset would thus determine the geographical and complexity scale. Just as an IEA effort does not have to address all management options simultaneously, the implementation of EBM does not need to incorporate all possible stakeholder sectors. Using the IEA process to address EBFM reflects this approach.

Ultimately, the best approach forward may be to apply multiple IEAs throughout an LME, each scaled for the decision-making process that it is attempting to inform. The convenient umbrella term "integrated ecosystem assessment" should thus not be interpreted as *assessment of an ecosystem*, because the IEA framework (Figure 1; Levin *et al.*, 2009; Samhouri *et al.*, 2014) clearly describes *assessing an objective* in an *ecosystem context*. Multiple coordinated, on-going IEAs in a single system may be a particularly effective way of illuminating unforeseen tradeoffs across resources, human activities, ecosystem services, or other attributes with societal value. Applying multiple IEA processes within an LME in a hierarchical manner will ensure consistency for cross-comparisons and also allow for aggregation to examine a suite of management measures, including their synergistic and antagonistic effects.

As with IEA programs, we should discourage referring to a specific application or product as "*the* IEA." We have, for example, heard end users refer to highly visible IEA products like major summary documents or ecosystem status reports (ESRs) as "the IEA." There are several dangers here. First, such products rarely, if ever, represent complete iterations of the IEA loop shown in Figure 1; for example, ESRs compiled by IEA teams are often dominated by ecosystem indicator summaries, with only minimal incorporation of high-level ecosystem management objectives or formal risk assessment (Garfield and Harvey, 2016). Thus, referring to them as "the IEA" badly misrepresents the full scope and scale of IEA science, particularly the central objectives and the management-relevant synthesis products. Second, calling a single product "the IEA" may inaccurately suggest that the IEA effort for the application in question has been completed. For example, we are often asked, "When will the IEA be done?" Any perception that an IEA application has an endpoint concurrent with the completion of a single product should be avoided. As we have noted throughout, the IEA process is iterative by definition (Levin *et al.*, 2009; Dickey-Collas, 2014; Levin *et al.*, 2014), and the nature of virtually any EBM issue will change continuously due to environmental variation, additional stressors or drivers, changes in activity of one or more human use sectors, changes in societal norms and preferences, and so on. It is thus critically important to dispel any sense among researchers, policymakers, managers, and stakeholders that an IEA application has a finite endpoint. Furthermore, if the best approach going forward is for multiple IEA applications within a given ecosystem, then clearly no one of them can be "*the* IEA."

Moving forward: implementing IEA and operationalizing EBM

The distinctions above amount to more than semantics, because if the IEA approach is to be an effective tool in operationalizing EBM, then IEA scientists and end-users of IEA products must have a common expectation of how this tool is to be implemented. IEA is first and foremost a scientific process; up until now, significant research has been necessary to understand how IEA science can inform EBM decision-making. This knowledge has now matured to the point that management applications should be at the forefront of IEA efforts. This is all the more true because IEA science is intended to be rooted in management objectives (Figure 1). However, IEA and to a large extent EBM remain largely within the scientific realm. Thus, it is necessary to define how scientifically derived, mature IEA approaches, programs, and products fit into management-driven processes intended to operationalize and implement EBM.

One means by which scientists and managers can collaboratively define and implement IEA tools is to link them with the compatible stages of EBM policymaking (Table 1). Implementation of EBM within resource management is best viewed in steps, each with its own scientific requirements (Borgström *et al.*, 2015; Cormier *et al.*, 2016). As with the IEA approach, the EBM policy process starts with setting strategic goals. A geographically broad but low-complexity IEA application would contribute by developing conceptual models, assessing the status of ecological and socioeconomic indicators, and analysing risk to prioritize threats. Based upon these strategic goals, regional and cross-sectoral marine planning processes set tactical objectives in step two (DFO, 2007). Two scientific products from IEA are essential to inform the development of tactical objectives: holistic evaluation of different objectives to identify trade-offs and inconsistencies; and quantification of ecological and societal reference limits. The IEA process to inform tactical objectives needs to be more complex than for strategic goal-setting, because identifying trade-offs and reference limits requires significant data and a mechanistic understanding of the coupled natural-human system structure and function (Samhouri *et al.*, 2012; Samhouri and Levin, 2012). The third step is the development of management measures that enact binding decisions to achieve tactical objectives. Doing so requires management strategy evaluations (MSEs) that examine how or if the proposed management measure helps achieve the tactical objectives. Thus, an entire IEA process may not be required for informing management measures, but multiple complex MSEs are necessary. The fourth and final step calls for adaptive management, which is an explicit component of the inner loop of monitoring and evaluation within the IEA framework (Figure 1).

Implementing the IEA approach into EBM in the US via any policy framework will be challenged by legislative constraints that necessitate proactive adaptability and flexibility by scientists and managers. Despite more holistic executive ocean policies, US Federal legislation (such as MSA, or the Outer Continental Shelf Land Act, 43 U.S.C. § 1331) is inherently focused on narrow sets of activities and their management. While EBM is developed on the science side as a fully integrated approach, the managers will seek to operationalize EBM in response to sector-specific authorities. Successful use of the IEA approach is most likely when the scientists and managers work together from the beginning, with the managers driving the development of the targets. Implementing EBM based on broad authorities such as NEPA may be an easier path for the full IEA process.

Conclusions

Throughout the evolution of the IEA process—its framework, its programs, and its specific applications—an oft-cited strength has been its role in assimilating, standardizing, and maximizing the value of the vast amount of available information about a marine ecosystem (Levin *et al.*, 2009; Foley *et al.*, 2013; Dickey-Collas, 2014; Walther and Möllmann, 2014). If efficiency of information-gathering and transfer is to be, in fact, a strength of the approach, then all parties need to be clear about what the IEA tool is, how it is to be implemented, and what ends it can achieve. This can and possibly should include having resource managers serve on IEA leadership teams, on equal footing with principal investigators on the science side. This would ensure that IEA science is, literally,

Table 1. The four steps of ecosystem-based management (EBM) policymaking (derived from Cormier *et al.*, 2016), and related IEA activities and products that can support each step.

EBM Policymaking Activity	IEA Activities	Complexity	Geographic Scale	IEA Decision-Support Products
• Strategic Goal-Setting	• Define EBM Goals • Assess Ecosystem • Analyze Risk and Uncertainty	Low	Broad	• Conceptual models • Ecosystem status reports • Qualitative risk assessments prioritizing threats to the ecosystem
• Tactical Objectives	• Develop Indicators • Evaluate Scenarios	Moderate	Ecosystem-Level	• Quantified reference limits, including safe and just operating space • Evaluation of tactical objectives, identifying tradeoffs and inconsistencies
• Management Measures	• Evaluate Scenarios	High	Management- and Ecosystem-level	• Evaluation of individual management measures to determine progress toward and/or retreat from tactical objectives • Evaluation of suites of management measures at ecosystem scale
• Adaptive Management	• Monitoring & Evaluation	High	Management- and Ecosystem-level	• Evaluation of IEA products to improve IEA • Evaluation of predicted management impacts versus observed management impacts • Identification of high return on investment opportunities to improve management

applicable to EBM, and not merely relevant to EBM. By helping guide the IEA process from start to finish, resource managers increase the probability that the right information will be produced and delivered in the appropriate manner. Incorporating resource managers has other benefits. They provide intimate knowledge of realistic alternatives that should be evaluated during management strategy evaluation and they can ensure the appropriate indicators are included in the process to satisfactorily address their mandates and tactical objectives.

The viewpoints we express here add to an IEA literature that is largely existential (definitions, best practices, lessons learned, etc.); this reflects the fact that applied marine ecosystem science is a young field that is still trying to find its fit in the marine EBM domain. The youth of the field, and of the IEA approach, means there will be more such existential papers in the future, but we are hopeful that those papers will appear increasingly alongside papers that describe real-world IEA implementations, complete with information on how marine EBM objectives were served by the IEA framework, programs, and products.

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Contribution to the Themed Section: '*Case studies in operationalizing ecosystem-based management*'

Food for Thought

Moving from ecosystem-based policy objectives to operational implementation of ecosystem-based management measures

Roland Cormier,[1,*] Christopher R. Kelble,[2] M. Robin Anderson,[3] J. Icarus Allen,[4] Anthony Grehan,[5] and Ólavur Gregersen[6]

[1]*Helmholtz-Zentrum Geesthacht, Centre for Materials and Coastal Research, Institute for Coastal Research, Max-Planck-Straβe 1, 21502 Geesthacht, Germany*
[2]*NOAA, Atlantic Oceanographic and Meteorological Laboratory, Ocean Chemistry and Ecosystems Division, 4301 Rickenbacker Causeway, Miami, FL, USA*
[3]*Environmental Science Division, Science Branch, Fisheries and Oceans Canada, PO Box 5667, St. John's, NL A1C 5X1, Canada*
[4]*Plymouth Marine Laboratory, Prospect Place PL1 3DH, Plymouth, UK*
[5]*Earth and Ocean Sciences, School of Natural Sciences, National University of Ireland Galway, Room A107, University Road, Galway, Ireland H91 TK33*
[6]*Syntesa Paterns & Associates, Fyri Oman Brú2, FO-510 Cøta, Faroe Islands*

**Corresponding author: tel: +49 4152 87-1884; fax: +49 4152 87-41884; e-mail: Roland.Cormier@hzg.de*

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The aim of ecosystem-based management (EBM) is to maintain an ecosystem in a healthy, productive and resilient condition through the implementation of policies and management measures. Although cross-sectoral planning may be led by a planning competent authority, it is up to the sector competent authority to implement the necessary management measures within their operations to achieve EBM goals and objectives. We suggest that scientific impediments to EBM are no longer significant to implement EBM operationally. Instead, we consider that approaching EBM within current policy cycle approaches would provide the necessary policymaking process step to operationalize EBM. In addition to enabling and facilitating collaboration, exchange, understanding as promoted by EBM, policymaking processes also require that policy is to be implemented through programs, measures, procedures and controls that have expected outcomes to "*carry into effect*" the policy objective. We are of the view that moving EBM from planning and objective setting to operational implementation is a management problem solving issues instead of a scientific one.

Keywords: governance, implementation mechanisms, management measures, operational EBM, performance management, policy cycle.

Introduction

McLeod *et al.* (2005) defines ecosystem-based management (EBM) as an integrated approach to management that aims to maintain an ecosystem in a healthy, productive and resilient condition while providing the services that humans want and need. Although the aim of EBM is to sustain ecosystem composition, structure, and function, Christensen *et al.* (1996) stipulates that management is the implementation of policies, protocols, and practices, and made adaptable by monitoring and research to achieve explicit goals. Langeweg (1998) further argues that it is the integration of macro-economic and sector specific policies combined with management actions that control the sources and effects of environmental change that is needed to achieve ecosystem sustainability. Thus, it is ultimately reliant upon the implementation of management measures, procedures and practices for specific human activities that aim to achieve the goals of EBM (Christensen *et al.*, 1996; Langeweg, 1998).

There has now been over two decades of literature amassed on EBM and the underlying scientific research needed to support EBM. The scientific consensus for EBM has been clear for over a decade (McLeod *et al.*, 2005). There are numerous mandates in many parts of the global oceans calling for EBM to be implemented and made operational to improve the management of our coastal and marine ecosystems and resources (Ricketts and Harrison, 2007; EU MSFD, 2008; McFadden and Barnes, 2009; IOPTF, 2010). There are a couple published papers dispelling myths regarding the supposed impediments to implementing EBM (Murawski, 2007; Patrick and Link, 2015). Yet, there are few to no examples of EBM planning initiatives informed by ongoing advances in science that have been operationally implemented across multiple sectors (Browman and Stergiou, 2005; Espinosa-Romero *et al.*, 2011; Katsanevakis *et al.*, 2011; Halpern *et al.*, 2012; Carlman *et al.*, 2014).

We argue that the operational implementation of EBM is the later step of a policy cycle that is widely in practice in government and bureaucracies today. It has long been established that ecosystem research, stakeholder participation and spatial planning processes are practical outworkings of EBM (Mitchell, 2002; Crowder *et al.*, 2006; Koontz and Newig, 2014; Soma *et al.*, 2015). The outputs of a policy cycle include goals and objectives setting that are typically reflected in legislation from which regulatory policies are derived to impose restrictions or limitation upon human activities (Anderson, 2011). The mechanisms for implementing these goals and objectives can span the range from outright regulations to standards or guidelines (Cormier *et al.*, 2016). Marine planning and coastal zone management is technically a public policy-making processes (Ehler and Douvere, 2009; Sardá *et al.* 2014; Cormier *et al.*, 2015) where the key outputs include the setting of goals and ecosystem objectives for the protection, conservation, and use of the marine ecosystem (McLeod *et al.*, 2005; Douvere, 2008). In performance management, it is, however, operational outcomes that frame the accountability for the implementation of measures, procedures and controls to achieve the stated goals and objectives of the policy process (Baehler, 2003). Nested within the context of ecosystem objectives, operational outcomes could also frame the design of sector specific management measures needed to manage human activities to achieve EBM goals and objectives (Antunes and Santos, 1999; Runhaar, 2016).

We are proposing that EBM could overcome a primary impediment to operational implementation by adopting a policy cycle with particular attention to setting operational outcomes as requirements for sector specific management measures. Continuing the discussions held at a recent workshop on "Making the ecosystem approach operational" hosted by the Atlantic Ocean Research Alliance Coordination and International Council for the Exploration of the Sea (ICES, 2016), this paper introduces the basics of policy cycles and performance management and explores the potential of such an approach to further operational implementation of EBM.

Policy cycles and policy-making

Anderson (2011) defines policy as "*a relatively stable, purposive course of action or inaction followed by an actor or set of actors in dealing with a problem or matter of concern*". He further explains that policy is what is actually done instead of something being proposed or intended and he differentiates policy from decision which is a specific choice among alternatives. In a political system, policy-making is a process of identifying a problem and setting public policy priorities, goals, and objectives. These then lead to the formulation of alternative courses of action that could resolve the problem and the eventual adoption of a specific course(s) of action to achieve objectives in support of the goals. In practice, the policy is implemented through programs, measures, procedures and controls that have expected outcomes to "*carry into effect*" the policy objective. Evaluation closes the policy cycle to determine what the policy is accomplishing and improve the policy or change the course of action where needed.

In performance management, goals and objectives provide the necessary direction for the development of outcomes (Bunker, 1972). Goals are usually derived from a mandate or vision statement providing the direction for a given course of action (Ackoff, 1990). Once goals are defined, objectives express what needs to be accomplished to reach the goals. Outcomes provide the measurable effects of management regimes in practice (Lupe and Hill, 2016). Outcomes are evaluated through performance measures that compare indicators against a benchmark as a measure of achieving an objective. When the benchmark is not met, the management regime needs to be re-assessed or the goals and objectives re-examined (Behn, 2003; Poister, 2010). Although goals and objectives are extremely important, it is the programs and their performance measures that will inform the organization and its clients as to the performance of a given program in achieving objectives (Fielden *et al.*, 2007; Tung *et al.*, 2014).

Policy cycle and ecosystem approach to management

Adopting the policy cycle to implement EBM could be relatively straightforward (Figure 1) and lead to the enactment of management measures that aim to achieve the EBM objectives and goals so often defined in marine planning exercises. An EBM policy cycle consists of similar components as the management phases proposed by Borgström *et al.* (2015) for EBM. However, Borgström *et al.* (2015) viewed these components as a heuristic model approximating a continuum of management rather than distinct phases. Although this may be accurate in EBM implementation to date, there is significant value to be gained from viewing these components of the policy cycle as distinct activities with their own inputs, processes, and outputs. By defining the policy process as consisting of discrete activities it makes it clear what is needed from the policy process to operationalize EBM and how ecosystem science, integrated assessments and state of the oceans reports would be key scientific activities to identify problems to inform the policy process. Without this clear distinction of policy activities, it is likely that EBM will continue to lack the specific management measures and operational outcomes necessary to achieve the objectives and goals defined in marine planning activities. Marine planning initiatives, almost uniformly across the globe, do not have the authority to implement the specific management measures necessary to achieve the EBM goals and objectives articulated by their plans, because these authorities still reside within single sectors (Sardá *et al.*, 2014). A policy process where marine planning is then used to inform operational outcomes and the management measures intended to achieve

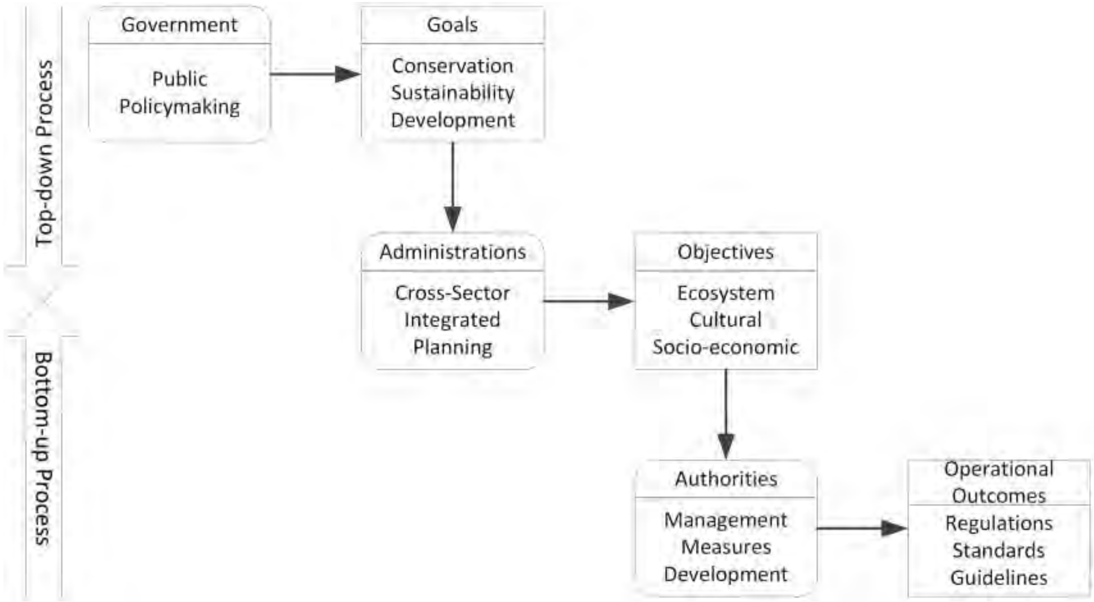

Figure 1. EBM meta-logic policy cycle.

these outcomes within single sectors could help overcome this impediment to operational EBM.

The policy cycle spans the spectrum from top-down to bottom-up processes as you move from strategic visionary goal-setting through planning into the implementation of specific management measures. From a top down perspective, government-led public policy-making processes set long-term goals for conservation, sustainability and development. These are typically reflected in legislation and may be prompted by national or international agreements (e.g. EU MSFD, 2008; Aichi Biodiversity Targets, 2012; UN SDG, 2015). Then, administrations or bureaucracies do the cross-sectoral planning and set regional ecosystem, cultural, social and economic objectives within the goals and mandate delegated to them by governments as the competent cross-sectoral authority to lead the planning. Planning uses decision support tools and stakeholder participation processes to facilitate the adoption of a specific course of action expressed as ecosystem objectives and applicable to all human activities operating within a given region or planning area. Once the objectives are set, the focus shifts to the developing of operational outcomes and environmental targets in collaboration with competent authorities of specific sectors to develop management measures. From a bottom up perspective, it would be the implementation of programs, measures and controls that would operationalize these plans against measurable expected outcomes to achieve the ecosystem objectives. It is important to note that it is the competent authorities of specific sectors that are accountable to implement the measures that are designed to manage their specific operations. Thus, it is the operational outcomes and environmental targets that provide the basis for an operational ecosystem approach to management. Without the integration of operational outcomes and objectives, any management measures developed under a given plan will likely have no relevance to the objectives and "*carry no effect*" in achieving them. Evaluations, based on ecosystem monitoring and compliance surveillance that assess if the ecosystem objectives are being achieved, provides the basis for adaptive management to close the policy cycle.

Generally, policy goals, objectives and outcomes are found in marine legislation and policies. As such, scientists should look in legislation and policy where the goals for the ecosystem have been articulated (Loomis and Paterson, 2014). However, they are not necessarily explicitly articulated, which often contributes to the confusion of what a given EBM initiative is to accomplish. For example, the goals of the EU Marine Strategy Framework Directive (EU MSFD, 2008) may be considered as "Paragraph 4: *Thematic strategy for the protection and conservation of the marine environment that has been developed with the overall aim of promoting sustainable use of the seas and conserving marine ecosystems*". The objectives can be found in "Annex I: *Quantitative descriptors for determining good environmental status*" while the operational outcomes may be found in "Annex VI: *Programmes of measures*" with the performance benchmarks defined as "Annex IV: *Indicative list of characteristics to be taken into account for setting environmental target*" needed by the "Annex V: *Monitoring Programmes*" to evaluate the performance of the programmes of measures. Although the Marine Strategy Framework Directive is a top-down piece of legislation, it is the programme of measures that "*carry into effect*" the bottom-up implementation of the ecosystem approach to management from an operational perspective.

Knowledge input in policymaking

The type of science required at each step of the policymaking process differs greatly because of the broad scope of the questions being asked (Table 1) (Campbell-Keller, 2009). At the onset of the public policymaking phase of the process, the role of scientific knowledge generated through research is to educate and inform the public and the political system as well as influence the agenda and priorities of a given government. This is one of the most important roles that science plays in society. This includes socio-economics providing the scientific information and influence for

Table 1. The science inputs into each activity of the policymaking process and the scientific products that should be developed to inform and implement the activity.

Activity	Science input	Science products
Strategic goal-setting	(i) Status and Trends of ecosystem and socioeconomic indicators;	(i) Ecosystem Status Reports;
	(ii) Prioritized threats to ecosystems;	(ii) Ecosystem Vulnerability/Risk Assessments;
	(iii) Identify opportunities to improve socioeconomic and ecosystem status	(iii) Indicators, Performance Measures, and Targets
Tactical objectives	(i) Evaluations of the ecological, cultural, social, and economic impacts of different objectives and actions;	(i) Define the Ecosystem's Safe and Just Operating Space with referenced limits;
		(ii) Trade-off analyses of objectives;
	(ii) Define Ecosystem Reference Points	(iii) Indicators, Performance Measures, and Targets
Management measures	(i) Predict impact of a management measure or suite of management measures to achieve cross sector objectives;	(i) Socio-Ecological Management Strategy Evaluations of proposed management measures;
		(ii) Risk of management measures to breach a reference limit;
	(ii) Evaluate proposed management measures ability to achieve prioritized objectives of stakeholders and managers	(iii) Comparison of alternative management measures against weighted objective priorities
Adaptive management	(i) Effective monitoring plan;	(i) Communication of ecological, cultural, social, and economic benefits and costs of the implemented management;
	(ii) Comprehensive evaluation of management effectiveness;	
	(iii) evaluation of alternative management options;	(ii) Socio-ecological Adaptive Management Scenario Evaluations;
	(iv) evaluation of scientific advice input into the policymaking process	(iii) Recommendations on how to improve scientific input into policymaking

development. The inputs include knowledge on ecosystem processes, state of the environment reporting, trends in ecosystem health, assessments of vulnerability to human induced stressors, socio-economic overview and development trends, and emerging technologies and investment opportunities, to name a few. The outputs of this step are mostly expressed in international and transboundary agreements, legislation and public policy regarding conservation, sustainability and development policy goals.

During the cross-sector integrated planning phase, the role of science is to provide advice and conduct decision analysis within the scope of the objectives being considered (Browman and Stergiou, 2005; Rice *et al.*, 2005; Rice, 2011) to reach the goals set in the prior step. Multi-Criteria Decision Analysis (MCDA) can be employed to help agencies and stakeholders set objectives based on potential scenarios and their relative values to an array of stakeholders (Huang *et al.*, 2011). The scientific analyses should then evaluate these objectives and priorities to inform managers and stakeholders of the ecological, cultural, social and economic repercussions of various objectives and courses of actions being considered in the planning within the context of the desired goals and to identify trade-offs or inconsistencies among the objectives. One of the initial science roles in setting objectives is to define the safe and just operating space for all of objectives being considered in the socio-ecological system. Using the boundaries of the safe and just operating space as reference limits not to be exceeded while developing objectives will ensure that devastating ecological, social, cultural, and economic repercussions are avoided (Raworth, 2012; Steffen *et al.*, 2015). The scientific advice does not make the decision, but provides evidence to inform the decision. For example, these would include the ecosystem basis of the potential impacts, the cultural basis of the changes to local communities, and the costs and benefits for society and economies as a whole. The inputs are in the form of future scenario evaluations, integrated ecosystems assessments, cumulative effects and impacts assessments, ecosystem, cultural and socio-economic overview reports, conservation and protection objectives, return on investment analysis and return on investment opportunities, and ecosystem risk assessments to name a few. The outputs of this step are typically in the form of integrated oceans and coastal management plans, marine spatial plans, protection and conservation plans for habitat and species, socio-economic objectives, and traditional and cultural objectives. Science needs to develop indicators and targets to assess and evaluate the performance of the management plan in achieving the objectives.

The development of management measures requires science to provide advice regarding the technical design and effectiveness of the proposed measures and to assess the efficacy of the suite of management measures. Economic and engineering considerations provide advice as to the implementation feasibility of the measures within an operational context. In an ecosystem-based operational context, the expected outcomes of operational management measures have to be consistent with and contribute to the planning objectives even though the measures are to be designed and implemented on a sector by sector basis. Such an approach ensures that the goals and operational objectives are operationally integrated with the specific development goals of a sector. Outcome-based indicators are used to measure performance in achieving objectives as determined by environmental targets. Such indicators are not designed to study trends or explain ecosystem processes or states. However, they must be placed in the context of such processes or states, laying the foundation for efficient and effective monitoring plans.

Monitoring must be designed to inform the different steps of the decision-making playing a central role in evaluating the performance of the management system and reviewing goals, objectives and outcomes in line with adaptive management principles. This is essential for EBM. Scientifically, we will never have all of the information to be absolutely certain of all of the implications of a proposed management measure. Different monitoring approaches are needed to determine if the goals, objectives, and outcomes are being achieved. For example, ecosystem science and ecosystem monitoring of trends, state changes, or shifts play an important role in reviewing public policy goals while regional integrated ecosystem and socio-economic assessments play an equivalent role in reviewing planning objectives. In an operational context however, assessments of stressors, effects, impacts and consequences also have to be paired with an evaluation of the effectiveness and feasibility of implemented management measures based on conformity assessments. The effectiveness and accuracy of the ecosystem science used to inform the process must also be evaluated and improved through this adaptive management and monitoring process (Levin *et al.*, 2014). It is the combination of monitoring and such surveillance that provides the basis for adaptive management by evaluating the performance of the management plan at achieving the objectives set in planning and, thus, in meeting its goals.

Concluding remarks

Although this discussion has artificially separated the science as an input into the policymaking process, it is critical that the science be developed in close collaboration with managers and policymakers to ensure that the most relevant science is being conducted and delivered into the policymaking meta-logic process displayed in Figure 1.

As discussed in the workshop, we still are lacking examples of operational, cross-sectoral EBM in marine and coastal ecosystems. This could be in part, because we don't have any clear cases where the policy process has been completed to implement EBM (Table 2). International agreements and marine planning policies have generated experience and best practices in the setting of ecosystem, cultural and socio-economic goals and objectives in countries around the world coupled with sound scientific research and knowledge in support of such initiatives. However, reviews of EBM have often cited a lack of guidance on how to implement EBM or a lack of specificity in objectives significant weaknesses (Foley *et al.*, 2013; Stelzenmüller *et al.*, 2013). We believe there is a disconnect between these EBM goals and objectives and within sectoral authorities charged with enacting management measures to achieve these objectives. This is why we propose the use of the policymaking process that explicitly states the need to institute management measures and operational outcomes to operationalize EBM. If followed, it will result in specific management measures being implemented by the appropriate authorities that are designed to achieve the EBM goals and objectives identified in numerous planning activities for marine EBM.

The scientific basis for EBM has been well established and continues to grow. This has resulted in considerable progress in the development of scientific frameworks and processes needed to undertake the science for an ecosystem-based approach to the management of human activities (Fletcher *et al.*, 2014; Samhouri *et al.*, 2014). These efforts have resulted in the mature development and implementation of many of the scientific methods needed to produce the required scientific inputs into the policy process. Moreover, many of these scientific products are already being operationally used for resource management, either within a single sector or for ecosystem restoration (Table 2). This suggests the scientific impediments to EBM are no longer significant.

Legislative and governance impediments may lie in the lack of legislative authorities needed to develop and implement the management measures to achieve the EBM objectives operationally. Legislation mostly provides the authority to lead and undertake ecosystem-based planning, such as the Oceans Act in Canada, The National Ocean Policy in the United States, and the Marine Strategic Framework Directive in Europe. This leaves the development and implementation of management measures to sector specific legislative authorities based on policy principles of collaboration leading to a mismatch between mandate, policy, authority, and operational implementation of the ecosystem approach.

Table 2. Examples of unclear cases completed policy processes and implementation of EBM.

Policy cycle activities	Science products	Operational	Reference(s)
Strategic goal-setting	Indicators, Risk Assessment, Socioecological Management Strategy Evaluation	No	Fletcher *et al.* (2014)
Strategic goal-setting		Yes, but too vague to be practically useful	Puget Sound Partnership (2006)
Strategic goal-setting		No	IOPTF (2010)
Strategic goal setting		In Progress	EU MSFD (2008)
Strategic goal-setting; operational objectives	Trade-off Analyses, Indicators	No	DFO (2005)
Adaptive management; management measures		Yes, in traditional exclusive use governance in Oceania	Aswani *et al.* (2012)
Adaptive management		Yes, for Ecosystem Restoration	Thom *et al.* (2016); LoSchiavo *et al.* (2013)
	Ecosystem Status Report	Yes, within a single sector in California Current and Alaska	Karnauskas *et al.* (2013); Zador *et al.* (2016); Garfield and Harvey (2016)
	Ecosystem Vulnerability/Risk Assessment	No	Samhouri and Levin (2012); Halpern *et al.* (2007, 2009); Cook *et al.* (2014); Teck *et al.* (2010)
	Indicators, Performance Measures, and Targets	Yes, for Ecosystem Restoration and single sector	Doren *et al.* (2009); Levin and Schwing (2011); Samhouri *et al.* (2011)
	Define Safe and Just Operating Space	No	Dearing *et al.* (2014); Raworth (2012)
	Trade-off Analyses (Ecosystem Services)	No	Lester *et al.* (2013); White *et al.* (2012)

Without legislative authority for management measures consistent with cross sector integrated planning, institutions currently involved in planning may not have the necessary governance processes or even the competencies needed to move from planning objectives to management measures and operational outcomes for EBM implementation.

This is placing unfounded responsibilities on the scientists leaving them to delve into the policymaking realm and figure out what to do as stakeholder and public awareness of issues and concerns increases. Although the scientific frameworks of EBM begins with defining ecosystem goals and objectives (Levin et al., 2008, 2009, 2014), it is the role of science to inform the policymaking process that develops these and not to develop the goals, objectives and outcomes. Scientists need to develop a sound understanding of policymaking to ensure that their advice is relevant to the decisions at hand (Burgman and Yemshanov, 2013). There is a need to include operational frameworks and procedures within current marine planning processes that overcome the lack of legislative authority within cross sector governance structures. There may also be a need for new education, professional training and development for managers, stakeholders and scientists in policymaking processes to understand the importance of implementation mechanisms of operational implementation such as regulations, standards, and guidelines.

Managers and stakeholders need to understand their information needs and, more importantly, the questions that need to be answered by the sciences and technical fields in order to pull through the relevant knowledge. Without this understanding, the scientist is left, not only to decide what information is needed for decisions, but is tasked with ensuring that this knowledge is transferred to the managers and stakeholders; thus, perpetuating, albeit unintentionally, the current debate as to whether or not sciences are providing adequate policy relevant information and whether or not managers are listening to science advice. In addition, a common or harmonized lexicon of terminology would facilitate the dialogue between scientists, technical experts, stakeholders and managers. This has been attempted with respect to indicator terminologies in the social and natural sciences (Loomis *et al*., 2014), but needs to be broadened to include experts from management, policy, engineering, etc. In fact, the most valuable aspect of international standards is most often found in the harmonized processes and standardized vocabulary (ISO 2009a,b).

Existing sustainability policies and planning processes have been addressing the first two steps of the policymaking process for EBM. It is the third step that now needs to take place focusing managers, stakeholders, scientists, and technical experts on the development and implementation of operational management measures to achieve the planning objectives. As ecosystem features, functions, and components are the basis for ecosystem-based planning and management, the effectiveness and feasibility of the implemented management measures are the basis for operational EBM. Goals and objectives alone cannot manage human activities. The intent of transparency, ethics and fairness in decision-making are the challenges found in any such processes involving multiple interests and perceptions. Processes such as public policymaking enable and facilitate collaboration, exchange, and understanding needed to provide assurance that decisions are made transparently, ethically and equitably. Making EBM operational today, has more to do with a management paradigm than a scientific and technical one.

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Contribution to the Themed Section: '*Case studies in operationalizing ecosystem-based management*'

Editor's Choice

International perceptions of an integrated, multi-sectoral, ecosystem approach to management

Anthony R. Marshak[1,*], Jason S. Link[2], Rebecca Shuford[1], Mark E. Monaco[3], Ellen Johannesen[4], Gabriella Bianchi[5], M. Robin Anderson[6], Erik Olsen[7], David C. Smith[8,9], Joern O. Schmidt[10] and Mark Dickey-Collas[4,11]

[1]*Office of Science and Technology, National Marine Fisheries Service, NOAA, 1315 East-West Highway F/ST4, Silver Spring, MD 20910, USA*
[2]*National Marine Fisheries Service, NOAA, 166 Water St, Woods Hole, MA 02543, USA*
[3]*NOAA National Centers for Coastal Ocean Science, 1305 East West Highway, Silver Spring, MD 20910, USA*
[4]*International Council for the Exploration of the Sea, Copenhagen, Denmark*
[5]*Fisheries and Aquaculture Department, Food and Agriculture Organization, Viale delle Terme di Caracalla, Rome, 00153, Italy*
[6]*Marine Habitat Division, Fisheries and Oceans Canada, P.O. Box 5667, St. John's, NL A1C 5X1, Canada*
[7]*Institute of Marine Research, PB 1870 Nordnes, Bergen N5817, Norway*
[8]*CSIRO Oceans and Atmosphere, Hobart, Tasmania 7001, Australia*
[9]*Centre for Marine Socio-ecology, University of Tasmania, Hobart, Tasmania 7001, Australia*
[10]*Department of Economics, University of Kiel, Wilhelm-Seelig-Platz 1, Kiel 24118, Germany*
[11]*DTU Aqua National Institute of Aquatic Resources, Technical University of Denmark, Jægersborg Alle 1, 2920, Charlottenlund, Denmark*

**Corresponding author: tel: +13014278208; fax: +13017131875; e-mail: tony.marshak@noaa.gov*

Marshak, A. R., Link, J. S., Shuford, R., Monaco, M. E., Johannesen, E., Bianchi, G., Anderson, M. R., Olsen, E., Smith, D. C., Schmidt, J. O. and Dickey-Collas, M. International perceptions of an integrated, multi-sectoral, ecosystem approach to management. – ICES Journal of Marine Science, 74: 414–420.

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The Ecosystem Approach to Management (EAM) has emerged over the past decades, largely to promote biodiversity conservation, and more recently sectoral tradeoffs in the management of marine ecosystems. To ascertain the state of practice of EAM operationalization, a workshop was held, which included a pre-workshop online survey. The survey gauged international participants' perspectives regarding capacity, knowledge, and application of EAM. When asked about the subject, most survey respondents had a general understanding of EAM, and provided a clear definition. Major perceived challenges to EAM objectives by those surveyed included limited knowledge, conflicting interests, insufficient communication, and limited organizational legal frameworks or governance structures. Of those directly involved in an ecosystem approach, the majority responded that processes were in place or developed for application of integrated knowledge toward assessing key issues within their respective sectors (i.e. fisheries, conservation, energy), and that capacity was generally high. Our results show that most respondents, irrespective of sector or geography, see value in considering an integrated, broader ecosystem approach as they manage their sector. Although many participants were from the North Atlantic region, our results suggest that much of the international community is converging toward continued understanding of broad-scale, integrated approaches to marine resource management.

Keywords: ecosystem approach to management, ecosystem-based management, multisector; ocean use, sector tradeoffs.

Introduction

There have been numerous calls for conducting an Ecosystem Approach to Management (EAM) of marine systems, also known as Ecosystem-Based Management (EBM), in the literature for the past decade or more (Christensen *et al.*, 1996; Larkin 1996; Botsford *et al.*, 1997; McLeod and Leslie, 2009; Curtin and Prellezo, 2010). The term EAM is used here. Elements of why, when, and what pertaining to EAM have been discussed in the literature (de la Mare, 2005; Hirshfield, 2005; Apitz *et al.*, 2006; Arkema *et al.*, 2006; Murawksi, 2007; Curtin and Prellezo, 2010), as well as some clarifying elements of linguistic uncertainty (Link and Browman, 2014). It is clear that the discipline and practice of EAM is now at the point of exploring the how-to of executing EAM, and continues to evolve from its original intent of conserving biodiversity (CBD, 2004), into other avenues such as addressing sectoral tradeoffs in marine ecosystem management (FAO, 2009). Certainly many elements of the suggested protocols, processes, and applications are congealing around accepted, recommended best-practices (ICES, 2005; Crowder and Norse, 2008; Pitcher *et al.*, 2009; Tallis *et al.*, 2010; Poe *et al.*, 2013; Long *et al.*, 2015). It therefore seemed timely to examine if there are lessons learned from nascent examples where EAM has been attempted, and to build upon past review efforts (Bianchi and Skjoldal, 2008).

A workshop held in January of 2016 sought to take stock of the state of practice of EAM in the marine environment, from multiple geographies and multiple jurisdictions (ICES, 2016). This workshop was supported by the Atlantic Ocean Research Alliance (AORA) Coordination and Support Action, and the European Union's Horizon 2020 research and innovation program. Complementary support for the workshop came from the Food and Agricultural Organization (FAO), Canadian Department of Fisheries and Oceans (DFO), National Oceanic and Atmospheric Administration (NOAA), and International Council for the Exploration of the Seas (ICES), with additional contributions from the OSPAR (Oslo-Paris) Commission and the Baltic Marine Environment Protection Commission – Helsinki Commission (HELCOM), and was aimed at a multi-sectoral suite of personnel associated with studying, managing and using various components of the ocean. The workshop sought to bring together a diverse group of experts, practitioners, stakeholders, and affected parties to discuss a myriad of considerations relative to EAM (*sensu* Browman and Stergiou, 2004; McLeod and Leslie, 2009; ICES, 2016). Of particular emphasis was the state of practice and identification of major impediments for fuller adoption and implementation of EAM.

Prior to this workshop, an online survey was distributed to all participants. The survey was designed to capture the perspectives from a wide-range of disciplines and ocean-use sectors concerning the state of application of EAM. Here we present those results as illustrative of how operational EAM is at the present moment, with additional input into the state of practice of the discipline.

Methods

An online survey was developed to solicit input from workshop participants, including responses from individuals specifically targeted by workshop organizers (Supplementary Table S1), to examine perceptions of capacity, knowledge, and application of EAM within specific case studies, and allow for subsequent discussion at the workshop. The survey consisted of 27 questions (Supplementary Table S2), and additionally asked respondents about their opinions regarding a range of EAM options. This targeted survey approach is commonly adopted (Evans and Mathur, 2005), had careful question design for its intended audience, planned intersection among questions, and sought to solicit thorough input and commentary beyond the ranking responses (Fowler, 2013). Such approaches have been used before in similar contexts in order to gauge regional and international stakeholder perspectives on environmental policies and EAM (Quinn and Theberge, 2004; Jennings and van Putten, 2006; Lawrence *et al.*, 2010; Biedron and Knuth, 2016). The poll was conducted online via a Sharepoint application, with an emailed link sent to all registered workshop participants and case study presenters.

Individuals within specific occupational roles from pre-defined sectors including conservation, fisheries, oil and gas, and renewable energy were surveyed as to their engagement and understanding of an integrated, multisector ecosystem approach, its value, and overall application within their respective sectors. Those who were directly involved in an ecosystem approach to science or management were queried as to their specific regional case studies, the processes involved in carrying out their work, and in applying the generated knowledge toward integrated multi-sectorial EAM arrangements, applications, decision making, and capacity. Additionally, all respondents were asked to rank and score effective ways to improve an ecosystem approach, with their range of responses pre-binned into four selected categories of improvements, and to comment upon perceived impediments and challenges to EAM.

Responses were quantified and summarized into common overarching themes, and reported as frequencies or percentages of those surveyed (Fowler, 2013). Although further statistics are possible, here we report on basic summary statistics to elucidate major themes and patterns.

Results

The majority of survey participants ($n = 51$) were scientists and researchers (58%) from the fisheries and conservation sectors (Figure 1). Most respondents were from the European Union (EU), Norway, Canada, and the United States, although there were a few from other locales (e.g. South Africa, South America, Australia). All representatives from the fisheries sector were directly involved in an ecosystem approach to science or management, while involvement was more evenly divided among members of the conservation community, and resource managers. Overall, there was low survey participation from NGO representatives, and members of the industrial, commercial, oil and gas, and renewable energy sectors. Main outputs, products, and services identified within participant sectors (Table 1) included fisheries, marine transportation, food supply and aquaculture, and petroleum and renewable energy. However, 21% of those surveyed did not provide an answer. When asked about their knowledge of the subject, most survey respondents had a general understanding of EAM, and were able to provide a clear definition (55%), although nearly 40% of respondents chose not to answer this question. Participants emphasized that key components to the ecosystem approach included sustainable human uses, spatial or areal considerations, marine systems, and integrated management frameworks (Figure 2). Complementary workshop discussions (see ICES, 2016) also highlighted the importance of goals that included: sustainability and resilience, environmental stewardship, human well-being, and jurisdictional, social, and

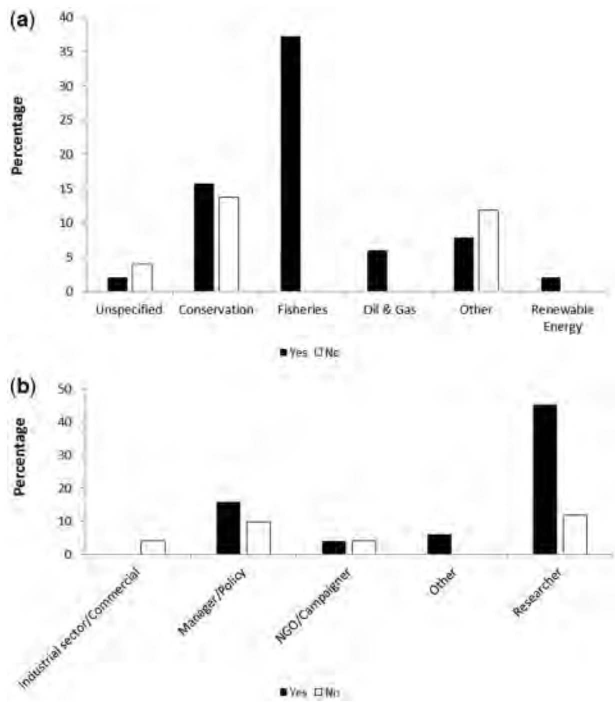

Figure 1. Percent (of total) of surveyed participants ($n = 51$) from their respective **(a)** sectors, **(b)** roles, and their direct involvement in an ecosystem approach (Yes/No).

Table 1. Main outputs, products, and services identified by survey participants ($n = 51$) within their sectors.

Major sector output	Frequency	Percentage
No answer	24	21.2
Fisheries	19	16.8
Marine transportation	14	12.4
Food supply and aquaculture	12	10.6
Petroleum and renewable energy	10	8.8
Tourism	9	8.0
Conservation and ecosystem services	7	6.2
Education and research	7	6.2
Recreation	6	5.3
Economies	5	4.4

Values denote the frequency and cumulative percent breakdown of their multiple responses within collective themes.

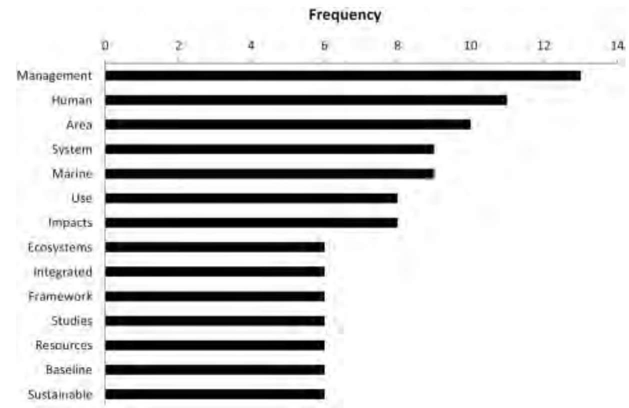

Figure 2. Major terms used by survey participants ($n = 51$) to describe an ecosystem approach.

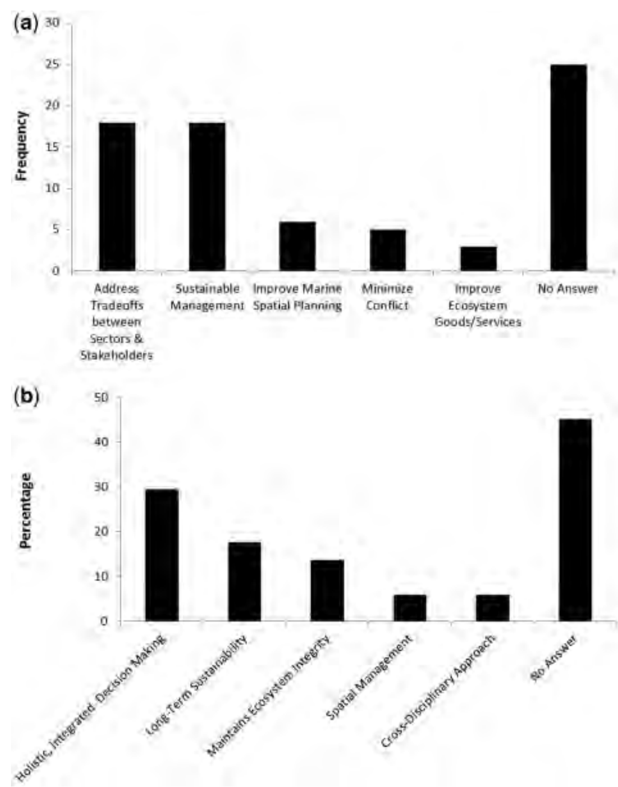

Figure 3. (a) Survey participants' ($n = 51$) perceptions of the benefits of integrated cross-sector management. Values denote the frequency of their multiple responses within collective themes. **(b)** Percent breakdown of survey participants' identification of the main value of an ecosystem approach.

geo-spatiotemporal components for multi-sector management. Adding to the definition, additional components within a given system should include ecosystem functions, interactions and services, and human dimensions, while applied processes should account for increased knowledge, participatory approaches, adaptive management, and cross-sectoral tradeoffs based on values. Participants commented that the knowledge that is generated from an ecosystem approach should be applied toward enhancing understanding of the given system, and for assessing tradeoffs in conjunction with a participatory approach by stakeholders and sectoral representatives.

Among multiple answers provided by each survey participant, major perceived benefits of integrated cross-sector management included the ability to address tradeoffs between sectors and stakeholders, and a means to work toward sustainable resource management (Figure 3a). When participants were asked to identify the main value of an ecosystem approach (Figure 3b), common replies included the ability to allow for holistic, integrated decision making, create long-term sustainability, and maintain ecosystem integrity. However, most frequently there was no response to either of these two questions.

Table 2. Perceived impediments and challenges to EBM objectives, and average scored rankings (±1 SE; Scores ranged from 1 -low to 5 -high) of survey-suggested effective improvements to an ecosystem approach, by participants (n = 51).

Perceived impediments and challenges	**Percentage**
Lack of knowledge	28.2
Conflicting interests and timelines	15.4
Lack of communication or collaboration	12.8
Lack of organizational or legal framework	12.8
Environmentally unsustainable practices	7.7
Lack of resources	7.7
Scientifically unsound management strategies	5.1
Suggested Improvements to an Ecosystem Approach	**Score**
Improved science/knowledge to inform decisions	4.3 ± 0.19
Improved planning of marine areas use	4.1 ± 0.16
Improved stakeholder consultation	3.9 ± 0.17
Improved legal frameworks	3.8 ± 0.21

Table 3. Responses of surveyed participants directly involved in an ecosystem approach ($n = 21$) as to the development of processes in their sector for focused integrated knowledge.

Integrated knowledge focus	Developed processes	Limited/in development	No formal processes
Impacts of various activities on marine ecosystems	61.9	33.3	4.8
Ecological, social, and economic tradeoffs of ecosystem strategies	47.6	19.0	33.3
Directly assessing human impacts and applied decision making	57.1	38.1	4.8
Sector-level management in a multi-sector EAM framework	52.4	23.8	23.8
Capacity for EBM	61.9	28.6	9.5

When responses were synthesized, major perceived impediments and challenges to EAM objectives by those surveyed (Table 2) included lack of knowledge, conflicting interests, lack of communication, and a lack of organizational or legal frameworks. However, additional commentary from participants highlighted that "definition of conflict" also emerged as a critical component. Of the four factors posed regarding effective improvements to the ecosystem approach, all factors were ranked and scored as equally important to surveyed participants.

Of those surveyed who were directly involved in an ecosystem approach to science or management ($n = 21$), the majority of individuals responded that processes were in place or developed to allow for application of integrated knowledge toward assessing several key issues within their respective sectors (Table 3). Over 60% of these respondents answered that processes exist to generate knowledge on marine ecosystem impacts of human and natural activities. However, 38% also responded that these processes still need more development, and while certain means to generate knowledge on ecological and socioeconomic tradeoffs are currently in place in some areas (48%), further work is needed. Additionally, participants responded that less formalized processes exist to incorporate sector-level management into a multi-sector EAM framework, including processes that allow for data and information uptake, advice formulation, decision implementation, process review, and application of this information to assess impacts and decision-making. Respondents from the United States and Europe did generally remark that its incorporation played a medium to strong role in their regions. However, most respondents (71%), irrespective of sector or geography, saw great value in considering a broader range of issues as they manage their sector. Although the majority of respondents answered that processes were in place to allow for direct assessment of human impacts and the quality of applied decision making, 43% replied that processes were still limited or non-existent. Overall, EAM capacity within science, policy, and management fields was perceived to be well developed and high, with European and United States respondents indicating that their capacities were strongest. Globally speaking, however, many regions are still developing their EAM capacities, with 62% of respondents characterizing their capacities as "good to high", with emerging international frameworks and processes to facilitate and integrate knowledge in varying stages of development (Table 4).

Additionally, of those directly involved in ecosystem approaches, their described categorical case study subjects (Figure 4) were mostly working on marine resource planning, an Ecosystem Approach to Fisheries (EAF), or environmental management, and specific science and management within identified regional ecosystems. The majority of US oil and gas sector interests are applied to marine resource planning, while the conservation sector was most focused on specific regional ecosystems. Often case studies were specific within a given sector, with the fisheries sector predominantly focused on EAF, while a few members of the conservation sector also focused on EAF, marine resource planning, and the design of Marine Protected Areas. Although most participants were from fisheries and conservation sectors, it warrants noting that most groups or sectors were at least represented and covered a wide range of issues.

Discussion

A variety of case studies from multiple sectors was examined in this survey, and our results suggest that most respondents, irrespective of sector, or geography, see value in considering an integrated, broader ecosystem approach as they manage their sectors. Most of the international community is converging on an understanding of EAM despite linguistic, process, and operational uncertainty (Arkema *et al.*, 2006; Barnes and McFadden, 2007; Curtin and Prellezo, 2010; Link and Browman, 2014), and there is mutual agreement on the importance of more holistic approaches to marine EBM within a given region. There is sufficient capacity to move forward with EAM in some regions, including the United States and western Europe, but current limitations to implementation include a continued lack of formalized legal frameworks for assessing tradeoffs among sectoral objectives (Apitz *et al.*, 2006; Tallis *et al.*, 2010), and perceived lack of knowledge (but see Patrick and Link, 2015). Our findings reveal that processes are in place in many regions and sectors to operationalize an ecosystem approach, particularly the development and implementation of Integrated Ecosystem Assessments (Levin *et al.*, 2009, 2013; ICES 2015). These processes may be less pronounced when applied directly toward ecological and socioeconomic tradeoffs, as observed in past critiques (Crowder

Table 4. Responses of surveyed participants directly involved in an EAM ($n = 21$) as to the details of its operationalization in their regions.

Region	Set up of multi-sectoral arrangement	Processes to facilitate generation of knowledge	Processes to integrate knowledge into EAM	Multi-sector processes for data uptake, advice, and decision implementation
Australia	Legislated and scientific institutional frameworks.	End-to-end ecosystem models and collaboration with resource managers/industry.	Science-led collaborations, mechanisms, and research on use/adoption of risk management standards, and on how to operationalize EBM.	Variable depending on legislative or policy framework. Research plays an important role in decisions.
Canada	Network of RFMOs (including NAFO) to deliver effective EAF.	Developing assessments to examine socioeconomic and stakeholder tradeoffs. Using multispecies ecosystem models.	Science products reviewed and used for elaboration of scientific advice through working groups, although much knowledge is still being identified.	Scientific advisory councils advising RFMO fishery commission, with input a critical component in decision making.
Europe	Research networks approach biodiversity issues, and integrate ecosystem-based approaches into environmental and fisheries management.	Developing models and metrics to measure socioeconomic tradeoffs between environmental efforts, and risk management processes.	Multi-disciplinary working groups assessing integrated impacts with datasets on environmental/human impacts/pressures and cross-sector integration.	Decision making and review within legislative and regulatory, managerial frameworks and committees, but implementations being developed.
South Africa	Comprised of intergovernmental commissions, NGOs, institutions, industrial and fishing alliances.	Fund academic and some governmental research through institutions and initiatives.	None mentioned	Departmental governmental framework, but mostly ad-hoc practices and participation in international forums for fisheries and seafood safety management.
USA	Federal agencies working in fisheries management, conservation, marine energy.	Government research into human activities, community engagement, ecosystem characterization, integrated ecosystem assessments, and ecosystem services tradeoffs.	Fund scientific study, multisector review, support cross-sectoral assessments and scientific investigation of system-level ecological and socioecological impacts.	Formalized, localized review of fisheries management plans and actions, stakeholder engagement, managerial bodies and councils to examine tradeoffs. Available information is regularly used in decision making.

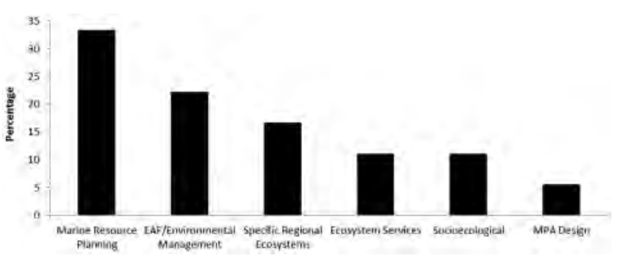

Figure 4. Percent breakdown of specific case study categories for surveyed participants directly involved in an EAM ($n = 18$).

and Norse, 2008; Thrush and Dayton, 2010; Poe *et al.*, 2013), but protocols and examples for doing so are continuing to emerge. There is strong agreement among participants that continued development of EAM toward assisting in minimization of conflicts, and in resolving sectoral tradeoffs, is key to its success. Additionally, these findings improve upon a past assessment of international EBM implementation (Pitcher *et al.*, 2009) that characterized only four of 33 evaluated countries as "adequate", and no country as "good" for EBM implementation, but could also reflect individual bias in self assessment and be dependent on geography.

The main impediments to implementing EAM were perceived lack of knowledge, conflicting interests, lack of organizational/legal framework, and lack of communication. Subsequent discussion at the workshop highlighted that "lack of framework" and "definition of conflict" emerged as critical considerations to overcome for future, additional application of EAM. However, the discussion highlighted that the lack of information and communication impediments are continually being overcome (ICES, 2016). The challenges for establishing a clear governance structure to adopt EAM remain, but key steps are being taken in many jurisdictions. For instance, explicitly examining and incorporating ecosystem considerations (often phrased in the context of ecosystem goods and services) is a core facet of the Marine Strategy Framework Directive in the EU (O'Higgins and Gilbert, 2014), Oceans Act in Canada (Jessen, 2011), Australia Oceans Policy (Vince *et al.*, 2015), the Norwegian Integrated Management plans (Olsen *et al.*, 2007, 2015), the National Ocean Policy (National Ocean Council, 2013), and Ecosystem-Based Fisheries Management Policy (NOAA, 2016) in the United States. The overarching IEA approach (Levin, *et al.*, 2009, 2013; ICES, 2015) holds promise as a means to have an analytical framework from which conflicts and tradeoffs can be usefully and equitably addressed.

Responses from surveyed participants were largely from researchers within fisheries and conservation sectors. As a corollary, industrial sectors were not well represented by survey participants, which is a direct reflection of the limited workshop participants. These results are not surprising given the natural resource genesis of EAM, and its development in the management sector (Grumbine, 1994; Yaffee, 1996, 1999), and also highlight the need for a more focused, yet broadly applied engagement strategy for a wider group of ocean researchers, users and managers. Case studies continue to emerge that demonstrate concrete advantages of utilizing and operationalizing EAM, and recommendations for its effective implementation (Österblom *et al.*, 2010; Butler *et al.*, 2013). Continued communication of these successes allows for their increased awareness among sectors, and together with socio-economic impact assessments of practices, can lead to increased application of ecosystem-based, holistic management and marine spatial planning scenarios. As future relevant case studies become available, it would be beneficial to potentially conduct a repeated workshop effort, where improved efforts to facilitate participation of broader sectorial representatives who are applying EAM approaches could occur.

In order to advance EAM, there remains a need for the EAM community to continue educating multiple sectors about the benefits of EAM and applying EAM beyond solely a fisheries management and conservation focus. This is highlighted by the sectoral focus just mentioned, low numbers of survey respondents for EAM practitioner questions, and often unanswered key questions by participants about their perceptions and valuation of an ecosystem approach. Non-responses to several questions may represent a lack of application of key components in a given region or sector, or unfamiliarity with ecosystem approaches within the prescribed categories by respondents. Additionally, continued research into ecosystem function in a given area, and means to assess sociological tradeoffs of ecosystem strategies, including multi-sectoral approaches to EAM, will greatly enhance its practice and evaluation. Example studies that address sectorial costs and benefits of an ecosystem approach include those by Österblom *et al.* (2010) and Butler *et al.* (2013) who specify recommendations for effective implementation of EAM toward nutrient mitigation, fisheries co-management, and coastal zone planning in the Baltic and Great Barrier Reef, Australia regions, respectively. Based upon our survey responses, the roles of sector-level management in EAM appear to be more defined and specified in both Europe and the United States, while less pronounced or responsive for Australia, Canada, South Africa, and South America. It is clear, however, that our findings do show that EAM is being applied within a variety of sectors, and where it is being considered, the participants strongly value an integrated broad-scale approach for management of their respective sectors.

The discipline and practice of EAM has come a long way from some of the earlier descriptions for the marine environment (e.g. Larkin 1996). Certainly there remains much work to be done, and many challenges and caveats persist in the face of increased implementation of EAM. Yet the results of this work show that compared with earlier assessments of the subject, progress is indeed being made, with emerging consensus throughout sectors not only on what EAM entails, and on what is needed to do it, but also on examples of where it is being put into practice.

Supplementary data

Supplementary material is available at the *ICESJMS* online version of the manuscript.

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Contribution to the Themed Section: '*Case studies in operationalizing ecosystem-based management*'

Original Article

Ecosystem considerations in Alaska: the value of qualitative assessments

Stephani G. Zador[1]*, Kirstin K. Holsman[1], Kerim Y. Aydin[1], and Sarah K. Gaichas[2]

[1]*Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way NE, Seattle, WA 98115, USA*

[2]*Ecosystem Assessment Program, Northeast Fisheries Science Center, National Marine Fisheries Service, NOAA, 166 Water Street, Woods Hole, MA 02543, USA*

**Corresponding author: tel: + 1-206-526-4693; fax: + 1-206-526-6723; e-mail: stephani.zador@noaa.gov.*

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The application of ecosystem considerations, and in particular ecosystem report cards, in federal groundfish fisheries management in Alaska can be described as an ecosystem approach to fisheries management (EAFM). Ecosystem information is provided to managers to establish an ecosystem context within which deliberations of fisheries quota occur. Our goal is to make the case for the need for qualitative ecosystem assessments in EAFM, specifically that qualitative synthesis has advantages worthy to keep a permanent place at the fisheries management table. These advantages include flexibility and speed in responding to and synthesizing new information from a variety of sources. First, we use the development of indicator-based ecosystem report cards as an example of adapting ecosystem information to management needs. Second, we review lessons learned and provide suggestions for best practices for applying EAFM to large and diverse fisheries in multiple marine ecosystems. Adapting ecosystem indicator information to better suit the needs of fisheries managers resulted in succinct report cards that summarize ecosystem trends, complementing more detailed ecosystem information to provide context for EAFM. There were several lessons learned in the process of developing the ecosystem report cards. The selection of indicators for each region was influenced by geography, the extent of scientific knowledge/data, and the particular expertise of the selection teams. Optimizing the opportunity to qualitatively incorporate ecosystem information into management decisions requires a good understanding of the management system in question. We found that frequent dialogue with managers and other stakeholders leads to adaptive products. We believe that there will always be a need for qualitative ecosystem assessment because it allows for rapid incorporation of new ideas and data and unexpected events. As we build modelling and predictive capacity, we will still need qualitative synthesis to capture events outside the bounds of current models and to detect impacts of the unexpected.

Keywords: Alaska, ecosystem approach to fisheries, ecosystem assessment, ecosystem-based fisheries management, ecosystem report cards.

Introduction

The high volume and high value commercial groundfish fisheries in Alaska are both biologically and economically important to the United States and managed through policies at the forefront of ecosystem-based fisheries management (EBFM) efforts. In 2014, these fisheries caught 2.25 million metric tons, with total ex-vessel value of $937.5 million (Fissel *et al.*, 2015) of species such as walleye pollock *Gadus chalcogramma*, Pacific cod *Gadus macrocephalus*, arrowtooth flounder *Atheresthes stomias*, sablefish *Anoplopoma fimbria*, and rockfish *Sebastes* spp. The fisheries are managed by the North Pacific Fishery Management Council (Council), one of eight regional councils established by the Magnuson-Stevens Fishery Conservation and Management Act in 1976 to manage fisheries in the 200-mile Exclusive Economic

Zone (NOAA, 2015). The Council reviews and manages fisheries issues in four large marine ecosystems (LMEs) in Alaska—the eastern Bering Sea (EBS), Aleutian Islands (AI), Gulf of Alaska (GOA), and Arctic—year-round but sets all quotas annually in December for the following year after review of individual stock assessments as well as economic and ecosystem information. Other important fish stocks in Alaska are directly managed by different entities (e.g. Pacific halibut *Hippoglossus stenolepis* by the International Pacific Halibut Commission and salmon *Oncorhynchus* spp. by the state of Alaska) but are under the purview of the Council as ecosystem or bycatch concerns.

Practicing sustainable fisheries, including conserving protected species and habitat is mandated in the United States, in particular under the 2006 amendment of the Magnuson-Stevens Fisheries Conservation and Management Act (1976). In most cases, achieving this goal requires inclusion of ecosystem and non-target species information into management decisions (Link, 2010; Link and Browman, 2014). There are multiple approaches for including ecosystem information in fisheries management, and Link (2010) delineates these approaches along a continuum from single-species fisheries management to ecosystem-based management (EBM). This includes ecosystem approach to fisheries management (EAFM)—where ecosystem information provides the context for single-species management advice; EBFM—where indirect and direct interactions between fisheries, non-target species, and ecosystem processes inform harvest recommendations; and EBM—where multisectoral trade-offs, pressures, and interactions are considered jointly (Link, 2010; Link and Browman, 2014). These approaches require a variety of tools, including risk assessments, management strategy evaluations, ecosystem models, and indicators (Smith *et al.*, 2007; Fulton *et al.*, 2011; Fay *et al.*, 2014; Plagányi *et al.*, 2014). Scientific advice can range from strategic (broad-scale) to tactical (directed at specific management decisions; Hollowed *et al.*, 2011; Plagányi *et al.*, 2014).

There is already a suite of policies and actions currently in practice in Alaska that might be characterized as EBFM or EAFM using these definitions. These include, for example, time and area closures, total fisheries catch limits, a ban on forage fish harvest, bycatch reduction measures, and modifications to fishing gear (Belgrano and Fowler, 2011). There are also regional fishery stock assessments that incorporate ecosystem data, and ecosystem-modelling activities aimed at including environmental pressures on evaluation of stock productivity and concomitant harvest recommendations. A Fisheries Ecosystem Plan was developed for the AI ecosystem in 2007 (AIFEP Team, 2007); another Fishery Ecosystem Plan is currently under development by the Council for the EBS. The Fishery Ecosystem Plan is expected to formalize and strengthen the delivery of ecosystem information to the Council [currently a cooperation between the ecosystem subcommittee of the Council and the Alaska Fisheries Science Center (AFSC) of the National Oceanic and Atmospheric Administration (NOAA)] and will provide a transparent tool for evaluating emergent trade-offs between conflicting management objectives (e.g. conservation and fisheries harvest) and for refining fisheries advice under changing climatic conditions.

The AFSC provides scientific information to the Council to inform the fisheries management process. Currently, one of the central avenues for providing ecosystem science to the Council is through an Ecosystem Considerations report that is presented to managers as part of the collection of stock assessments and economic data produced annually (Belgrano and Fowler, 2011; Zador, 2015). The Ecosystem Considerations report provides a review of ecosystem status as context for quota-setting deliberations, serving as a type of EAFM advice. The report has a long history with the Council, relative to other regions in the country. It was first produced in 1995 as a compendium of Alaska marine ecosystem information and discussion of EBM (Belgrano and Fowler, 2011). In its substantially revised current version, the report includes indicator-based assessments and report cards, and detailed contributions from a broad range of scientists that encompass survey data, model output, and derived ecosystem indicators. Ecosystem information is presented in varying levels of detail, from succinct report cards to detailed indicator descriptions. The information is compiled and synthesized, then presented sequentially for review to several Council bodies, most notably regional Plan Teams and the Scientific and Statistical Committee, which are composed of a diverse group of experts including scientists from government agencies and academia. The process of annual production and review results in the adaptive nature of the report, as evidenced by its evolution over the years. This allows the report to be flexible to new priorities, data, models, and needs as expressed through the frequent communication between AFSC scientists and the Council.

The goal of the Ecosystem Considerations report is to provide stronger links between ecosystem research and fishery management and to spur new understanding of the connections among ecosystem components by synthesizing results of many diverse research, survey, and modelling efforts (Zador, 2015). Trends are monitored with ecosystem indicators, defined here as simply a representation of an ecosystem component measured through time. Indicators can be based on data or derived values, represented in time-series format. They have been widely used to compare ecosystem status across and within ecosystems (Link, 2005; Shin *et al.*, 2010b) and serve as essential components in EAFM and integrated ecosystem assessments (Levin *et al.*, 2009; Fogarty, 2013). Methods for selecting indicators range from formalized processes such as the drivers, pressures, status, indicators, response (DPSIR) approach (Elliott, 2002; Livingston *et al.*, 2005) to surveys of experts (Teck *et al.*, 2010; but see Stier *et al.*, 2016). Indicators are used as an efficiency measure when the ecosystem component in question either cannot be measured directly or to forecast a future state. For example, annual abundances of large copepods may be represented by a time-series of trends in survey abundance. The trends in survey abundance of large copepods may foretell overwinter survival of age-0 walleye pollock (Heintz *et al.*, 2013), which in adult form comprise the second largest single-species fishery by biomass worldwide (FAO, 2014). In the context here, a good indicator is one in which there is clear understanding of what it representing, either as a prediction or description of an important ecosystem component (Link, 2010). Additionally, to be useful to management, indicators should be relevant within the management framework (Rice and Rochet, 2005). In this Alaska example, the annual management cycle necessitates indicators that are updatable annually and preferably not more than one calendar year old. Ecosystem information that represents older ecosystem status is useful in a heuristic sense but is not particularly relevant when quotas have already been set and fished.

Thus, the Ecosystem Considerations report, and the assessments and indicators contained within, are based on quantitative data and complex models but the information is applied as qualitative advice (i.e. to provide context for EAFM). When ecosystem status, and any potential concerns, are presented prior to the stock assessment harvest recommendations, the review of the quantitative harvest recommendations are evaluated in the context of the current status of the ecosystem. The evaluation is in the form of discussion among Council body members, which can influence the quota-setting process during deliberations, and is described further herein. An active area of research is the development of explicit ecosystem thresholds that trigger a specific management response, such as a percent decrease in quota (Large *et al.*, 2013; Fay *et al.*, 2014). Incorporation of these thresholds will change the nature of the application of ecosystem information in the future (Large *et al.*, 2013).

Our goal is to make the case for the need for qualitative ecosystem assessments in EBFM/EAFM, specifically that qualitative synthesis has advantages worthy to keep a permanent place at the fisheries management table, in concert with the development of quantitatively sophisticated modelling efforts. These advantages include flexibility and speed in responding to and synthesizing new information from a variety of sources. First, we use the development and production of indicator-based ecosystem report cards as a current, working example of adapting ecosystem information to management needs. In this particular case, report cards serve a need to succinctly summarize the ever-expanding ecosystem information available to fisheries managers. Second, we review lessons learned and provide suggestions for best practices for applying EAFM to large and diverse fisheries in multiple marine ecosystems.

Methods

In 2010, AFSC scientists met with the Council, to propose modifications to the existing method of conveying ecosystem status (the Ecosystem Considerations report) to improve its utility to the Council. Prior to 2010, the ecosystem indicators within the report were selected using the DPSIR approach (Elliott, 2002; Livingston *et al.*, 2005). Although this approach was able to identify myriad indicators of ecosystem change, many of the indices were repetitive and did not integrate multiple interactions into biological terms meaningful to fisheries managers. The AFSC scientists proposed a more regionalized approach to streamline and synthesize information at the ecologically based scale of LME (Figure 1), rather than at the fisheries management scales, some of which cross LMEs (e.g. the BSAI designation for a stock whose range is in both the Change to EBS and AI).

The general approach was to use teams of ecosystem experts to select short lists of indicators for the EBS, AI, and GOA LMEs. The top 8–10 selected indicators were used to develop succinct ecosystem report cards and serve as the basis for 5–10 page integrative ecosystem assessments. Candidate indicators were collated from existing indicators or knowledge of existing models and/or data that could be used to derive indicators. Indicators were sorted into broad categories: physical processes such as climate and oceanography, lower trophic organisms such as phytoplankton and zooplankton, benthic organisms, fish foraging guilds, seabirds, marine mammals, and human dimensions. Features of non-existent but desired indicators were suggested as needed to fill gaps or improve on existing indicators.

Participants on the expert teams were selected to represent diverse scientific, management, and fishing expertise in the ecosystems from within and outside AFSC. Teams were developed for the EBS in 2010, for the AI in 2011, and for the GOA in 2014–2015. Structuring themes were chosen to help guide indicator selection; these were "ecosystem productivity" for the EBS, "spatial variability" for the AI, and "complexity" for the GOA. Teams selected indicators either in person during 1–2 workshops or by voting in an online query. The goal of the workshops and online query was to determine the top ecosystem indicators to serve as vital signs for regional fisheries managers with respect to the structuring theme (see Results for the reasoning behind the theme selection). The top indicators for each category were selected by consensus for the EBS and AI, and by highest numbers of votes for the GOA. The selected indicators for the GOA were further refined by review of a group of 28 scientists involved in a co-occurring integrated ecosystem research program in the GOA.

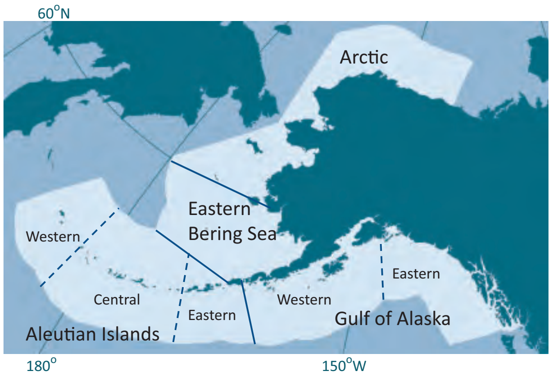

Figure 1. LMEs and ecoregion boundaries in Alaska. Highlighted area indicates the extent of the 200 nautical mile Exclusive Economic Zone.

The final lists of indicators were presented in report cards. Each report card is composed of the indicators and bulleted text; no "grades" or other type of comparable valuations are included despite the name. The indicators are displayed in an annualized time-series format that depicts the long-term mean, recent 5-year trend, and recent 5-year mean relative to long-term mean (Figure 2). Bulleted lists that accompany the time-series briefly summarize some or all of the following: status, factors influencing trends, and implications for fisheries managers. Further detail is contained within the associated ecosystem assessments, which qualitatively integrate information from the report cards with additional information from other indicators, observations, and model outputs in an expanded synthesis.

The report cards were first presented to the Council in the year that each was developed. The Council reviews provided suggestions that were incorporated into the development of subsequent report cards. All report card indicators were and continue to be updated as possible each year. Indicators are replaced if new methodologies or data become available to improve on the originally selected indicators. Expert teams are planned to reconvene periodically (∼5 years) to revisit the top indicators and propose modifications to the suite to reflect current knowledge.

Results

Adapting ecosystem indicator information to better suit the needs of fisheries managers in Alaska resulted in succinct report cards that summarize trends for the ecosystems in question, complementing more detailed ecosystem information presented to managers to provide context for EAFM/EBFM. The top indicators selected by the teams of ecosystem experts were presented on a single page (per ecosystem or ecoregion) with similar formatting to enable comparisons among indicators. The accompanying

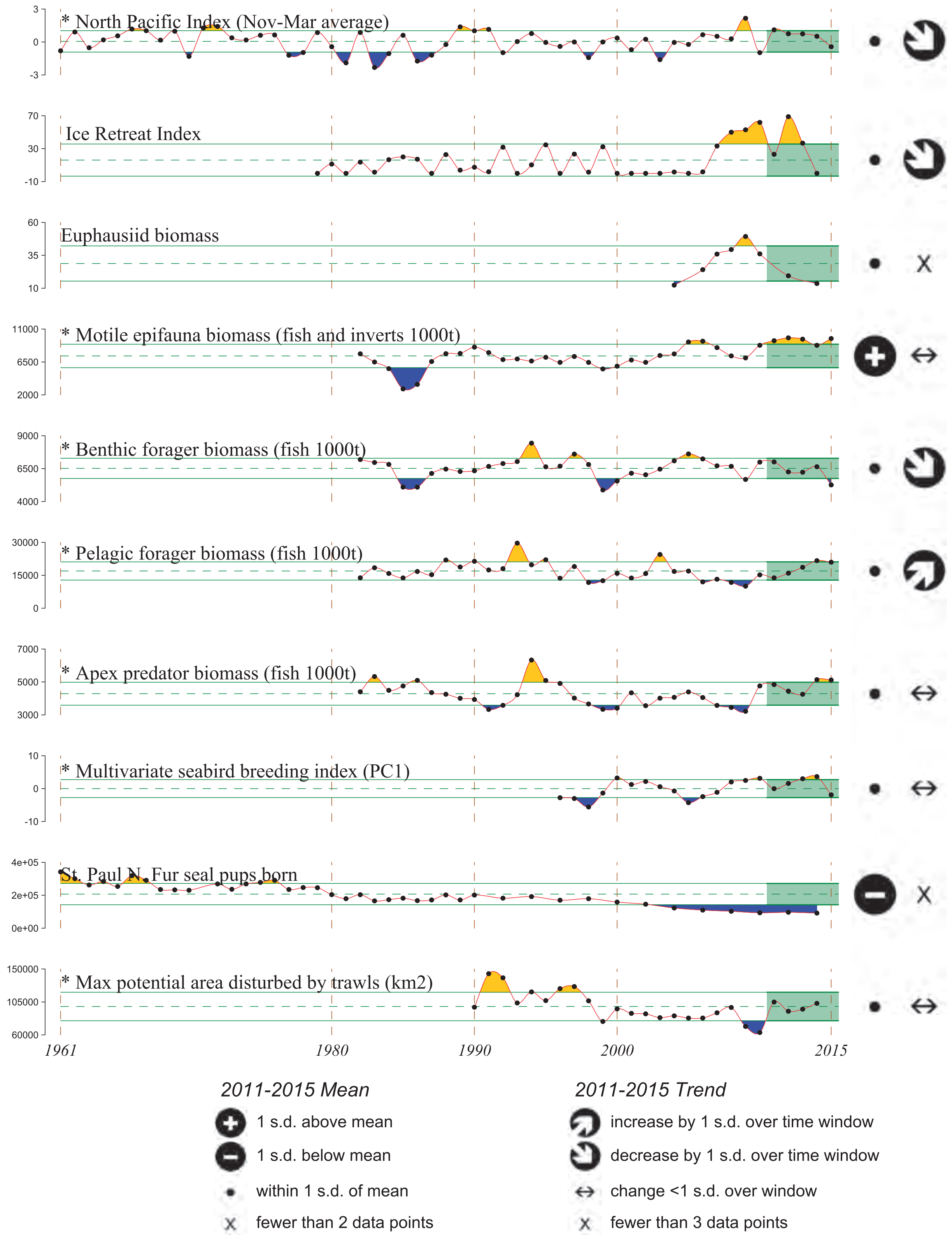

Figure 2. (a) The EBS Report Card. Time-series depict the long-term mean (dashed line), 1 *SD* (solid lines). The last 5 years are shaded. These values are used to calculate the symbols (available at http: http://access.afsc.noaa.gov/reem/ecoweb/Index.php).

Eastern Bering Sea 2015 Report Card

- The **eastern Bering Sea in 2015 was characterized by warm conditions** that were first seen in 2014, and continued through the winter, during which the **PDO reached the highest winter value seen** in the record extending back to 1900.
- The extent of **sea ice during winter was reduced, as was as the size of the cold pool of bottom water** relative to the long term mean during the summer.
- While there was no acoustic survey of euphausiids during summer, rough counts of zooplankton during spring indicated that **small copepods were more prevalent than either lipid-rich large copepods or euphausiids**.
- **Jellyfish remained abundant** during summer, following a new peak fall biomass recorded in 2014.
- **Survey biomass of motile epifauna has been above its long-term mean** since 2010, with no trend in the past 5 years. There has been a unimodal increase in brittle stars since 1989 and for sea urchins, sea cucumbers and sand dollars since 2004-2005.
- **Survey biomass of benthic foragers decreased substantially in 2015, which contributed to the change in their previously stable recent trend to negative.** Recent declines could possibly be related to the consecutive years of springtime drift patterns that have been linked with poor recruitment of flatfish.
- **Survey biomass of pelagic foragers has increased steadily** since 2009 and is currently above its 30-year mean. While this is primarily driven by the **increase in walleye pollock** from its historical low in the survey in 2009, it is also a result of **increases in capelin during the cold years**, which have remained high during the past two warm years.
- **Fish apex predator survey biomass is currently above its 30-year mean**, although the increasing trend seen in recent years has leveled off. **The increase from below average values in 2009** back towards the long term mean is driven primarily by increases in Pacific cod from low levels in the early 2000s.
- **The multivariate seabird breeding index is below the long term mean**, indicating that seabirds bred later and less successfully in 2015. This suggests that **foraging conditions were not favorable for piscivorous seabirds**, a hypothesis further supported by large numbers of dead, emaciated birds observed at sea.
- **Northern fur seal pup production for St. Paul Island remained low** in 2014, indicating that fewer pups were produced in 2014 than during the year of the last survey in 2012.
- The maximum potential **area of seafloor habitat disturbed by trawl gear has remained stable since 2011**.

Figure 2. (b) Summary text that accompanies the EBS report card (available at http: http://access.afsc.noaa.gov/reem/ecoweb/Index.php).

bulleted text provided highlights that could be explored further in the more in-depth ecosystem assessments and detailed indicators descriptions.

The teams of ecosystem experts selected a total of 10, 9, and 10 physical, trophic, and human dimensions indicators for the EBS, AI, and GOA ecosystems, respectively (Table 1). Although the process to generate the report cards was similar among the teams, the resulting products varied. Although each report card was composed of time-series and bulleted text, some LMEs had more than one report card. For the EBS, teams focused on broad, community-level indicators to determine the present state and likely future state of ecosystem productivity (Table 1). Thus, there was one report card to represent the southeastern Bering Shelf area. Following presentations and review of existing physical and biological data, the AI team concluded that significant spatial variability in trophic and physical conditions of the island chain ecosystem warranted grouping indicators by three ecoregions: western, central, and eastern (Figure 1). Ecosystem variability thus served as the structuring theme for indicator selection. Accordingly, the ideal suite of indicators were those for which there are data across all ecoregions and could characterize a global attribute with local behaviour. The final selection included eight indicators represented in three regional report cards and one broad scale climate indicator that could not be reduced into the ecoregion scale. The complexity of the GOA ecosystem, which includes a narrow shelf in the east and wide shelf in the west, major freshwater inputs and large islands and gullies that influence oceanography, allows local scale processes to swamp basin-wide signals. Thus, capturing this complexity was the structuring theme for indicator selection in the GOA and was represented in part by grouping indicators into two ecoregions: western and eastern (Figure 1), which were characterized in two report cards.

Selected indicators for all LMEs included a mix of primary indices (e.g. sea ice retreat timing) and those that integrate multiple processes [e.g. northern fur seal (*Callorhinus ursinus*) pup production] and reflect relative data-availability among LMEs (Supplementary Table S1). In general, the selected EBS indicators were more data-dependent, reflecting the extensive scientific sampling, and knowledge in the region. In contrast, the selected AI indicators were more integrative and indirect (e.g. planktivorous auklet *Aethia* spp. reproductive success as an indicator of zooplankton abundance), reflecting the relative paucity of data in the region. The teams aimed to select broad indicators responsive to changes in structuring processes and reflective of system-wide

Table 1. List of selected report card indicators and definitions.

LME	Indicator category	Indicator	Description
EBS			
	Climate	North Pacific index	November–March average of the area-weighted mean sea level pressure over the region 30°–65° N, 160° E–140° W
	Oceanography	Ice retreat index	The number of days during March and April in which there was at least 20% ice cover in a 100 km box around the M2 mooring located in the southeastern portion of the shelf at 57° N and 164° W
	Zooplankton	Euphausiid biomass	Acoustically determined euphausiid density (no. m^3) averaged over the water column
	Benthic	Motile epifauna biomass	Aggregated biomass of commercial and non-commercial crabs, sea stars, snails, octopuses, and other mobile benthic invertebrates determined from bottom trawl surveys
	Fish	Benthic forager biomass	Aggregated biomass of Bering Sea shelf flatfish species, juvenile arrowtooth flounder and sculpins from bottom trawl surveys
	Fish	Pelagic forager biomass	Aggregated biomass of adult and juvenile pollock, other forage fish such as herring, capelin, eulachon, and sand lance, pelagic rockfish, salmon, and squid from bottom trawl surveys
	Fish	Apex predator biomass	Aggregated biomass of Pacific cod, arrowtooth flounder, Kamchatka flounder, Pacific halibut, Alaska skate, and large sculpins from bottom trawl surveys
	Seabirds	Multivariate seabird breeding index	The dominant trend (first principal component) among 17 reproductive seabird datasets from the Pribilof Islands that include diving and surface-foraging seabirds
	Marine mammals	Northern fur seal pups	The number of fur seal pups born on St Paul Island
	Humans	Area disturbed by trawls	Area of sea floor estimated to be disturbed by trawl gear based on commercial fisheries observer data
AI			
	Climate	North Pacific index	November–March average of the area-weighted mean sea level pressure over the region 30°–65° N, 160° E–140° W
	Zooplankton/ seabirds	Auklet reproductive success	Reproductive success of zooplanktivorous crested *Aethia pusilla* and least auklets *Aethia cristatella*
	Forage fish/ seabirds	Gadids, sand lance *Ammodytes*, Hexagrammids	Percent composition of these forage fish delivered to tufted puffin *Fratercula cirrhata* chicks
	Fish	Pelagic forager biomass	Aggregated biomass of Atka mackerel, Pacific ocean perch, pollock, and northern rockfish from bottom trawl surveys
	Fish	Apex predator biomass	Aggregated biomass of Pacific cod, arrowtooth flounder, Kamchatka flounder, Pacific halibut, skates, large sculpins, rougheye, and black-spotted rockfish from bottom trawl surveys
	Marine mammals	Sea otters	Skiff-based survey counts
	Marine mammals	Steller sea lion non-pups	Counts of adults and juveniles from aerial surveys
	Humans	Area disturbed by trawls	Percent of shelf area deeper than 500 m trawled as determined from commercial fisheries observer data.
	Humans	K-12 school enrollment	The number of children enrolled in schools
GOA			
	Climate	Pacific decadal oscillation	The leading principal component of North Pacific monthly sea surface temperature variability (poleward of 20°N for the 1900–1993 period)
	Oceanography	Freshwater input	Fresh water discharge at the GAK 1 oceanographic station at the mouth of Resurrection Bay near Seward
	Zooplankton	Mesozooplankton biomass	Taxon-specific abundance data collected from Continuous Plankton Recorders
	Benthic	Copepod community size	Mean copepod community size as collected from Continuous Plantkton Recorders
	Fish	Motile epifauna biomass	Aggregated biomass of eelpouts, octopi, crab, sea stars, brittle stars, sea urchins, sand dollars, sea cucumbers, snails, and hermit crabs in bottom trawl surveys
	Forage fish	Capelin	Percent composition that was capelin in diets of tufted puffin *F. cirrhata* chicks at the Barren Islands
	Fish	Apex predator biomass	Aggregated biomass of Pacific cod, arrowtooth founder, halibut, sablefish, large sculpins, and skates in bottom trawl surveys
	Seabirds	Black-legged kittiwake reproductive success	Reproductive success of black-legged kittiwakes *Rissa tridactyla* at Chowiet Island
	Marine mammals	Steller sea lion non-pups	Counts of adults and juveniles from aerial surveys
	Humans	Population	The combined human population of Kodiak, Homer, Yakutat, and Sitka communities

Table **2**. Summary of ecosystem attributes, selection team participants, and indicator foci.

LME	EBS	AI	GOA
Habitat	Broad, flat, muddy shelf.	Extensive rocky island chain, deep trenches, oceanic basins	Broad and narrow shelf area, gullies, major river input, large, and small islands
Data	Extensive	Data-poor	Moderate
Team members:			
NOAA	17	10	23
Academia	2	4	4
Management	1[a]	1	[b]
Industry		1	
Other fed		2	8
Non-profit		1	2
Independent research		1	3
Structuring theme	Production	Variability	Complexity

[a]2 of the NOAA scientists also served on the Council Scientific and Statistical Committee.
[b]1 participating NOAA scientist also served on the Council Scientific and Statistical Committee.

impacts of fishing and climate rather than selecting indices based on data quality *per se* and/or spatial or temporal extent of datasets. Efforts were made to avoid redundancy in indices as well as highlight data gaps where indices lacked spatial or temporal coverage (e.g. indicator was measured in one region but not another).

Indicator selection also reflected the expertise of the teams (Table 2). After the first report card was produced, the Council recommended diversifying the team of experts used for subsequent report card development. Thus, the predominance of research scientists in the team that was convened for the EBS, was lessened for the AI with the inclusion of a commercial fisherman, conservation organization representative, and additional agency scientists. The inclusion of the human dimension indicator, AI school enrollment, resulted from the suggestion from the commercial fisherman. A greater effort to diversify the expertise for the GOA team was accomplished by changing the selection format to an online query, which had a response rate of 42%. This allowed both the number and diversity of team members to increase, although NOAA scientists comprised the majority of respondents.

Discussion

The application of ecosystem considerations, and in particular ecosystem report cards, in federal groundfish fisheries management in Alaska can be described as an EAFM (Link, 2010; Link and Browman, 2014). Ecosystem information is provided to managers (Council) to establish an ecosystem context within which deliberations of fisheries quota occur. This constitutes a qualitative application of quantitative data but with the flexibility and speed to incorporate new information from a variety of sources. For example, a recent warming event in the GOA developed in winter 2014 when surface temperatures were observed to be $>3^{\circ}$C above the previous highest recorded temperature (Bond *et al.*, 2015). Observations of immediate ecosystem impacts such as range shifts in highly mobile marine predators were tracked and presented that year to the Council; ecosystem indicator trends were qualitatively evaluated in light of the current unexpected environmental conditions. The AFSC was able to respond quickly to put resources towards more surveys the following summer because of a combination of quantitative forecasts, specifically the 9-month bottom temperature forecast for the EBS that is one of the indicators in the Ecosystem Considerations report, and qualitative information about how the ecosystem might respond to the continuation of warm conditions.

With support from the Council, the development of ecosystem report cards grew out of efforts to reduce myriad ecosystem indicators to a succinct summary that can be delivered to managers alongside more comprehensive information. Ecosystem report cards have been developed in many countries to address a variety of management objectives (see review in Dauvin *et al.*, 2008; Doren *et al.*, 2009; Connolly *et al.*, 2013). The specific goal in Alaska was to increase the visibility and utility of important ecosystem data, by making the information more consistently presented, transparent, and comparable between indices. These summaries, though not depicting quantitative scores or grades, give fisheries managers, or other interested parties, a quick way to review current ecosystem status relative to trends over time and note any warning signs. In theory, success could be measured by a documented increase in the number of views of the report cards or Council time spent discussing ecosystem information, which is currently unknown. However, an indirect measure of success could be inferred by the current development of similar report cards for individual groundfish and crab stocks in other divisions within AFSC, which the Council has encouraged. Additionally, similar formats have been adopted by NOAA efforts in the West Coast to inform the Pacific Fishery Management Council (Harvey *et al.*, 2014; Garfield and Harvey, 2016).

There were several lessons learned in the process of developing the ecosystem report cards for the EBS, AI, and GOA. First, despite using similar methods, the resulting products varied substantially among ecosystems. Most notably, while the EBS was presented in a single report card for the LME, the AI, and GOA were represented in 3 and 2 report cards, respectively, that capture ecoregion-scale differences within the LMEs. Second, the selection of indicators for each region was influenced by geography, the extent of scientific knowledge/data, and the particular expertise of the selection teams. Significant differences in physical habitat and ecosystem attributes limited generalizing indicators to a single suite across LMEs in the AI and GOA. Regions with less data available such as the AI led to selection of more integrative and indirect indicators. Finally, more diverse expertise in the selection teams led to more diverse indicators selected.

Understanding the management system

Optimizing the opportunity to incorporate ecosystem information into management decisions requires a good understanding of the management system in question. This understanding can help scientists to structure ecosystem information to best fit within the cycles and processes of the management system, which leads to more useful, and ultimately usable, information. In other words, it is likely more efficient to adapt scientific information to the spatial and temporal scales of the management system at hand, than to hope to adapt a management process to fit scientific data. This is particularly relevant to tactical management advice, which is geared towards specific and immediate needs of decision-makers, as opposed to strategic advice, which has relevance over longer time scales (Plagányi *et al.*, 2014). The need for regionally specific and adaptable ecosystem management tools has been widely documented (Smith *et al.*, 2007; Fulton *et al.*, 2011; Walther and Möllmann, 2013; Dickey-Collas, 2014). In the case of federal groundfish fishery management in Alaska, the annual cycle of stock assessment review and quota setting means that ecosystem indicators need to be up to date or at most a year old to be relevant to quota deliberations on present day conditions. Ecosystem information that is 2 or more years old retains heuristic value but less relevance to immediate management decisions as previous quotas have already been set and fished.

A small but important factor in communicating ecosystem information to fisheries managers is that the order of information delivery matters. Ecosystem information needs to be presented before quota setting to allow for qualitative inclusion by setting context for quota deliberations. Receiving reports or presentations after quota deliberations, whether separated by hours or months, creates a missed opportunity for contextual inclusion. Although this is particularly relevant with oral or other fixed-time presentations, it is also relevant to written communications that may be delivered at different times in a management process.

What has and has not worked

The abbreviated format of the report cards limits, by design, the amount of information that can be conveyed. They are too short to be complete representations of ecosystem state, but the accompanying text in the integrative ecosystem assessments allows for the addition of synthesis as well as the inclusion of new and noteworthy events or data that may signal red flags or issues that may influence management decisions, including those that are not standard annualized time-series. The report cards and assessments also serve as an organizing structure for connecting process research to management, with the result in this case that the Council is not isolated from the scientists.

For now, the delivery of information via the Ecosystem Considerations report remains firmly EAFM, in that explicit use of report cards for tactical quota decisions has not occurred due to lack of quantitative ecosystem thresholds but this is an active area of research (Large *et al.*, 2013; Fay *et al.*, 2014). This lack of established tactical application is the main challenge for qualitative assessments. Inclusion of qualitative assessments may be considered sufficient to define a management process as EAFM without explicit examples of how the information has influenced management. Although to date explicit examples are rare in Alaska's groundfish management, the inclusion of ecosystem information through discussion has led to quota adjustment in some years. The most clear example occurred in 2006, when a combination of modelling output and ecosystem indicator status led to a reduction of the quota of EBS walleye pollock from the amount recommended in the walleye pollock stock assessment model. In this case, the Council noted that: the results from the stock assessment indicated a 19% decline in the stock and a northward shift of some of the stock into Russian waters; ecosystem indicators showed a large decline in zooplankton, which are important prey for juveniles; and a multispecies model documenting increased predation by arrowtooth flounder on juvenile pollock. The qualitative combination of information was deemed sufficient justification to reduce the quota for the following year.

Regular presentation of ecosystem information may also have more indirect influence on management on a longer time frame. For example, in Alaska many commercially fished stocks share quota between two LMEs, such as sablefish in the EBS and AI. Regular discussion of the two LMEs that emphasize the difference between the LMEs may facilitate future discussions regarding splitting quota by these LMEs by establishing the differences in trends, as recently occurred with Pacific cod, whose AI stock, and allowable catch, is now assessed separately from the EBS (Thompson and Palsson, 2013).

Suggestions for best practices

Communication and visual presentation is important for making ecosystem information more useful (and concise, in the case of report cards), which in turn results in the product being used more (whether defined by inclusion in discussion or dissemination through multiple communication channels). Methods for presenting ecosystem information vary widely, from simple pie charts (Shin *et al.*, 2010a) and stoplight figures (Tierney *et al.*, 2009) to more complex, web-based platforms (e.g. the Chesapeake Bay Report Card; ecoreportcard.org/report-cards/chesapeake-bay, accessed 21 June 2016). We have found that frequent dialogue with managers and other stakeholders leads to adaptive products suited to the end user. In the case described here, the goal was to select indicators to best represent qualities of interest for the ecosystem in question. The resulting selection would have included different indicators if the goal was to be able to compare ecosystem states across ecosystems, such as is the case for efforts such as INDISEAS (www.indiseas.org) or the Ocean Health Index (www.oceanhealthindex.org; Shin *et al.*, 2010b; Halpern *et al.*, 2012).

In our experience, suggestions for best practices for incorporation ecosystem considerations into fisheries management include frequent communication, flexible products that allow for adaptation to both new management concerns and new scientific information, matching temporal and spatial scale of ecosystem information with the management process, and considering carefully the timing and order of how ecosystem information is presented to managers with respect to the management cycle. The initial buy-in from the primary stakeholder (Council) and frequent communication through the annual review cycle allows ecosystem products to be tailored to needs of federal fisheries managers in Alaska. One example is increasing interest in human dimensions (Hicks *et al.*, 2016). The inclusion of the AI school enrollment indicator in the AI report card received substantial questioning when introduced in 2011. In contrast, the further development of human dimension indicators was specifically requested when the first GOA report card was presented in 2015. In addition, we recommend incorporating a standardized process to document management responses to report cards and/or qualitative ecosystem assessments in general (Connolly *et al.*, 2013).

We believe that there will always be a need for qualitative ecosystem assessment, exemplified in this case by report cards of selected indicators or lengthier integrative ecosystem assessments, which can coexist with increasing model complexity and the development of ecosystem thresholds. Qualitative assessments allows for rapid incorporation of new ideas and data and unexpected events. There is lag time inherent in modelling efforts, specifically the design, development, and testing, which result in powerful tools for ecosystem management once in operation (Smith *et al.*, 2007; Link *et al.*, 2010; Fulton *et al.*, 2011). Models of intermediate complexity have been proposed to limit the complexity and support tactical fisheries management advice (Plagányi *et al.*, 2014). Nonetheless, as we build modelling and predictive capacity, we will still need qualitative synthesis to capture events outside the bounds of current models and to detect impacts of the unexpected.

Supplementary data

Supplementary material is available at the *ICESJMS* online version of the manuscript.

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Contribution to the Themed Section: '*Case studies in operationalizing ecosystem-based management*'

Original article

A continuous involvement of stakeholders promotes the ecosystem approach to fisheries in the 8-fjords area on the Swedish west coast

Andreas C. Bryhn[1]*, Karl Lundström[1], Amelie Johansson[1], Henrik Ragnarsson Stabo[2†], Henrik Svedäng[3]

[1]*Department of Aquatic Resources, Institute of Coastal Research, Swedish University of Agricultural Sciences, Skolgatan 6, 742 42 Öregrund, Sweden*
[2]*Department of Aquatic Resources, Institute of Freshwater Research, Swedish University of Agricultural Sciences, Stångholmsvägen 2, 178 93 Drottningholm, Sweden*
[3]*Department of Aquatic Resources, Institute of Marine Research, Swedish University of Agricultural Sciences, Turistgatan 5, 453 30 Lysekil, Sweden*

†Passed away during the course of the study.
**Corresponding author: tel: +46 10 4784152; fax: +46 10 4784157; e-mail: andreas.bryhn@slu.se.*

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The coastal marine environment in the 8-fjords area on the Swedish west coast has been subjected to various stakeholder co-management initiatives since 1999. Stakeholders and authorities have acted by supporting and implementing gradually stricter fishing restrictions following the collapse in the 1970s of several demersal fish stocks and their apparent lack of recovery. Moreover, concerns have been raised regarding a locally sharp depletion of eelgrass meadows, in addition to an apparent increase in the number of seals and cormorants. The present 8-fjords initiative applies a cross-sector approach to environmental management and thus also addresses various types of environmental pollution. This study has compared the environmental work around the 8-fjords to 15 principles regarding the ecosystem approach to fisheries (EAF). The main strength that has been identified among the EAF principles is the continuous involvement of stakeholders. Among weaknesses in the EAF is the scarcity of suitable indicators that are necessary for appropriate monitoring, especially biomasses of functional groups as well as economic and social indicators. Many environmental problems in the fjords remain and it is possible that improved adherence to EAF principles will facilitate solving some problems and alleviating others. Moreover, the application of the EAF in practice in the 8-fjords can serve as a guiding example for co-managing other aquatic ecosystems towards ecological, economic, and social sustainability. The experiences from the 8-fjords initiative, including its extensive stakeholder involvement, may serve as a practical EAF example to be studied by researchers and managers globally.

Keywords: coastal ecology, ecosystem approach, ecosystem-based management, fisheries, fjord system.

Introduction

The ecosystem approach to fisheries

Overfishing and degradation of coastal habitats have prompted extensive theoretical work on how an ecosystem approach to fisheries (EAF) can be applied. The EAF has been put forward as a more sustainable way to manage fisheries and ecosystems than traditional management approaches (Pikitch *et al.*, 2004; Zhou *et al.*, 2010; Fogarty, 2014). Difficulties in predicting changes in the ecosystems and complex relationships and interactions have contributed to some of the shortcomings in traditional management, which has typically focused on one species at a time and on fisheries as the only societal sector (CFEPTAP, 2006; Fogarty, 2014). Hitherto, ecology, sociology, and economics have only played a limited role in the management of ecosystems (Marasco *et al.*, 2007). The EAF is instead a way to attain ecologically, socially, and economically sustainable fisheries by taking whole ecosystems into account (Cochrane, 2002; FAO, 2003a, b; Pikitch *et al.*, 2004; Zhou *et al.*, 2010; Fogarty, 2014; Fulton *et al.*, 2014).

EAF principles

There are different definitions of the EAF. The present study uses 15 main principles for the EAF as determined by Long *et al.* (2015) from 13 selected key EAF references (e.g., FAO, 2003b; NOAA, 2007; CBD, 2016; Table 1).

(i) An ecosystem usually consists of fauna, flora, microorganisms, and non-living components that interact in a way that they form a functional unit (Tansley, 1935; World Resources Institute, 2005). Considering ecosystems connections means that focus should not primarily be on target species in commercial fisheries, but on all components and processes in the ecosystems (Pikitch *et al.*, 2004); e.g., other fish species, trophic relationships over the life-cycles, what regulates food availability and constraints in fish reproduction.

(ii) Ecosystems have dynamic properties due to the fact that many ecosystem features vary over time and space and in many cases they display a non-linear response to external changes (Håkanson *et al.*, 2010; Large *et al.*, 2013).

(iii) Acknowledging uncertainty that arises from measurement error, and assuring that the uncertainty in modelling how ecosystems respond to different types of management is quantified and communicated (Håkanson *et al.*, 2010; Large *et al.*, 2013).

(iv) To establish a practical limitation of the work and thereby substantiating the EAF, appropriate temporal, and spatial scales should be used.

(v) Delineation should be made with distinct boundaries. The choice of scale is affected by site-specific ecological and societal conditions (Long *et al.*, 2015). The spatial delineation may, for example, need to be adapted to the geographical extent of fish habitats and to administrative borders and multi-scale monitoring may be necessary in order to capture all relevant ecological processes (Lewis *et al.*, 1996) as well as economic and social processes (Leslie and McLeod, 2007).

Table 1. The 15 principles for the Ecosystem approach to fisheries used in this study.

Principle number	Principle name	In number of key references
i	Consider ecosystem connections	11
ii	Account for dynamic nature of ecosystems	8
iii	Acknowledge uncertainty	8
iv	Appropriate spatial and temporal scales	10
v	Distinct boundaries	8
vi	Adaptive management	9
vii	Integrated management	8
viii	Interdisciplinarity	8
ix	Recognise coupled social-ecological systems	8
x	Use of scientific knowledge	8
xi	Sustainability	8
xii	Stakeholder involvement	8
xiii	Decisions reflect societal choice	8
xiv	Ecologic integrity and biodiversity	8
xv	Appropriate monitoring	8

These principles were found in a majority of 13 key references according to Long *et al.* (2015).

(iv) Adaptive management is based on environmental monitoring, is evidence based and aims towards a process-based learning that adjusts management to new knowledge, changing conditions and towards decreasing uncertainty in measurements, predictions, and decisions (Engle *et al.*, 2011; Westgate *et al.*, 2013).

(vii) Integrated management means that management has a long-term perspective and is holistic, i.e., takes into account a wide range of knowledge from different disciplines, such as hydrology, ecology, biology, economics, sociology, and oceanography. Integrated management also incorporates the interaction between land and coastal waters, and between coastal waters and the sea (Engle *et al.*, 2011; Vallega, 2013).

(viii) Integrated management thus requires interdisciplinarity.

(ix) Connections between social and ecological systems have to be recognized. Ecosystems are continuously affected by human activities, while ecosystem services such as food production or provision of recreational opportunities affect society (World Resources Institute, 2005; Liquete *et al.*, 2013).

(x) Basing management on science ensures that the best available knowledge is integrated into decisions. Science promotes an increase in knowledge in a systematic way and lays the ground for new insights, methods, and technologies which are essential to meet societal and environmental challenges (UN, 2014). Science also increases the knowledge and understanding of interactions between society and nature, and may guide societal influence on nature in a sustainable direction (Kates *et al.*, 2001; Miller *et al.*, 2014).

(xi) Sustainability has been defined as development which meets the needs of today without jeopardising the ability of future generations to meet their needs (UN, 1987).

(xii) Cooperation between stakeholders and scientists has been suggested as the most effective way to manage fisheries and ecosystems (Mackinson *et al.*, 2011; Burger and Niles, 2013). Including stakeholders into fisheries management is therefore on the rise globally (Sandström *et al.*, 2015).

(xiii) Such inclusion can improve the way that decisions reflect society's choice (Mackinson *et al.*, 2011). Involving stakeholders in management and balancing their different interests regarding coastal environmental issues can even be considered a feature of democracy (Buanes *et al.*, 2004).

(xiv) Ecological integrity and biodiversity together form one of the principles. To safeguard ecologic integrity means protecting and promoting the ability of ecosystems to self-organize through their inherent processes and structures (Burkhard *et al.*, 2011). Biodiversity consists both of a structural diversity of molecules, genes, species and habitats, and of a functional diversity of processes and interactions within the ecosystems. Humans assign monetary and other values to biodiversity (Spash *et al.*, 2009), in addition to that biodiversity also shapes the structure and function of ecosystems (Cardinale *et al.*, 2012b).

(xv) Appropriate monitoring requires indicators that can be monitored (Schmitt and Osenberg, 1996). Indicators are thereby crucial for the practical success of an EAF (Jennings, 2005; Stelzenmüller *et al.*, 2013; Fay *et al.*, 2013; Vinueza *et al.*, 2014; Fulton *et al.*, 2014; Levin and Möllmann, 2015). Indicators provide information that describes states and changes in ecosystems and their interaction with society (Hall and Mainprize, 2004).

Ideally, there should be ecological, economic and social indicators (Leslie and McLeod, 2007). Examples of ecological indicators are the proportion of habitat coverage, the biomass of fish species (Fulton *et al.*, 2014), the number of species, the species composition in the ecosystem (Vinueza *et al.*, 2014), the mean length of species and their slope size spectrum (Link, 2005). For discussions on optimal quantitative indicators for the impact of fisheries on ecosystems, see e.g. Link (2005) and Methratta and Link (2006).

The 8-fjords area

There is a need to demonstrate how EAF policies may be applied in practice (Long *et al.*, 2015; Patrick and Link, 2015). The inshore area between the islands Tjörn and Orust and the Swedish mainland, in the province of Bohuslän on the Swedish west coast, is called the 8-fjords area, as it consists of the eight fjords: By, Havsten, Halse, Askerö, Kalvö, Stig, Hake, and Älgö (Figure 1). Since 1999, these fjords have been subjected to various stakeholder co-management initiatives, and five municipalities have made a joint effort to create the so-called 8-fjords initiative focusing on managing fisheries and ecosystems in the fjords. Lately, attempts have been made to include additional fjords such as the Koljö fjord north of the Orust island as well as coastal waters south of the Älgö fjord down to River Nordre Älv (57°48'N, 11°49'E) in the joint management (Johansson, 2015). One of the main aims within the 8-fjords initiative has been to enable a recovery of collapsed local demersal fish stocks (Degerman, 1983; Svedäng *et al.*, 2001; Svedäng, 2003; Bartolino *et al.*, 2012; Cardinale *et al.*, 2012a), primarily through implementation of rigorous fishery restrictions. A second concern has been a drastic decline in seagrass cover in parts of the 8-fjords, partly since seagrass beds are essential for recruitment of many fish species (Nyqvist *et al.*, 2009; Baden *et al.*, 2012). Related management goals are productive and fishable demersal stocks and beneficial conditions for seagrass beds to recover. Predation from seal and cormorant populations is a third concern that has been suggested to prevent demersal fish stock recovery. Regarding seals and cormorants, no management goals have been set and improved data collection is considered to have first priority at present. Furthermore, the 8-fjords initiative works with several additional marine environmental issues such as eutrophication and marine litter (Johansson, 2015).

Objective of the study

The objective of this study is to assess how the management of the 8-fjords conforms to EAF principles. The criteria for EAF used are the 15 principles outlined by Long *et al.* (2015). Furthermore, we intend to provide a background description of the 8-fjords initiative and to address the environmental issues that are at stake. The Swedish Agency of Marine and Water Management (SWaM) and researchers have selected the 8-fjords area as a suitable pilot study area for EAF work in Sweden. This study intends to benefit the 8-fjords initiative by making its work better known and by pointing out strengths and weaknesses of its achievements in an EAF perspective. Moreover, the study could provide helpful and constructive ideas regarding how the EAF can be applied in practice.

The 8-fjords initiative as a response to three environmental concerns

The 8-fjords have historically been very productive and have probably been fished ever since hunters-fishers-gatherers first settled in the area towards the end of the Weichselian ice age. During the 19th century, stock declines are believed to have forced local fishermen to gradually search for more remote fishing grounds in and far beyond the North Sea (Cardinale *et al.*, 2014). An even more dramatic fisheries driven change occurred around the end of the 1970s, when stocks of cod and other demersal fish collapsed, particularly in the 8-fjords area, but also in nearby waters (Degerman, 1983; Svedäng *et al.*, 2001; Svedäng, 2003; Svedäng and Bardon, 2003; Bartolino *et al.*, 2012; Cardinale *et al.*, 2012a). The absence of fishable stocks of cod, pollack and plaice in the 8-fjords area has thereby been disastrous to the local fishery and has profoundly changed its preconditions (Table 2). These stocks show no signs of recovery; however, recent investigations in 2013 and 2014 have shown abundance of cod eggs in early life stages (2–6 days old; Henrik Svedäng, pers. obs.) and mature cod, indicating that cod reproduction still occurs in the area, albeit to a very limited extent (Sköld *et al.*, 2008; 2011).

Table 2 also shows that while demersal fish catches have decreased dramatically, commercial catches of the pelagic species sprat and herring have increased. This increase could be related to higher local abundance of these pelagic species, possibly gaining from the coastal zone cod protection regulations (Swedish Board of Fisheries, 2009). The higher catches of the pelagic species might also be due to a higher fishing effort, as coastal herring and sprat are relatively important for Swedish coastal fishing since both species still occur abundantly in sheltered waters and are also of a better quality. In other words, the rather small-scale fishery on herring and sprat is still viable and profitable due to local circumstances. Sprat in the fjords may comprise local stocks, as their morphology, growth and reproductive effort differ from those of sprat in waters outside of the islands Tjörn and Orust (Molander, 1952; Vitale *et al.*, 2015). Similarly, the herring stocks along the Skagerrak coast also appear to be local and genetically differentiated (Ruzzante *et al.*, 2006).

The most recent example of more rigorous fishing restrictions is from 2010 when the Swedish Board of Fisheries and the 8-fjords initiative agreed to implement a no-take zone and a zone where only manual gear is allowed half a year in the Havsten fjord (Figure 2). The 8-fjords initiative stressed at the time that public support for the restrictions would be key to their success. In addition, in a larger zone covering the fjords Koljö, Havsten, By, Halse, Askerö, Kalvö, and Stig, fishing for cod, pollack, and haddock (*Melanogrammus aeglefinus*) is prohibited except when using manual gear or crustacean pots.

A second concern of the 8-fjords initiative has been the locally drastic decline of eelgrass (*Zostera marina*) beds (Nyqvist *et al.*, 2009; Baden *et al.*, 2012). Eelgrass is the dominating seagrass in the northern hemisphere, and is the only seagrass species in the 8-fjords (Nyqvist *et al.*, 2009). Eelgrass beds form three-dimensional habitats that are essential for many species and are therefore particularly essential to protect. Fry and juvenile fish can use eelgrass beds as feeding grounds and as protection against predators. Eelgrass beds can thus widen the bottleneck for survival that the fry and juvenile stages and their exposure to food constraints and predators comprise (Obaza *et al.*, 2015).

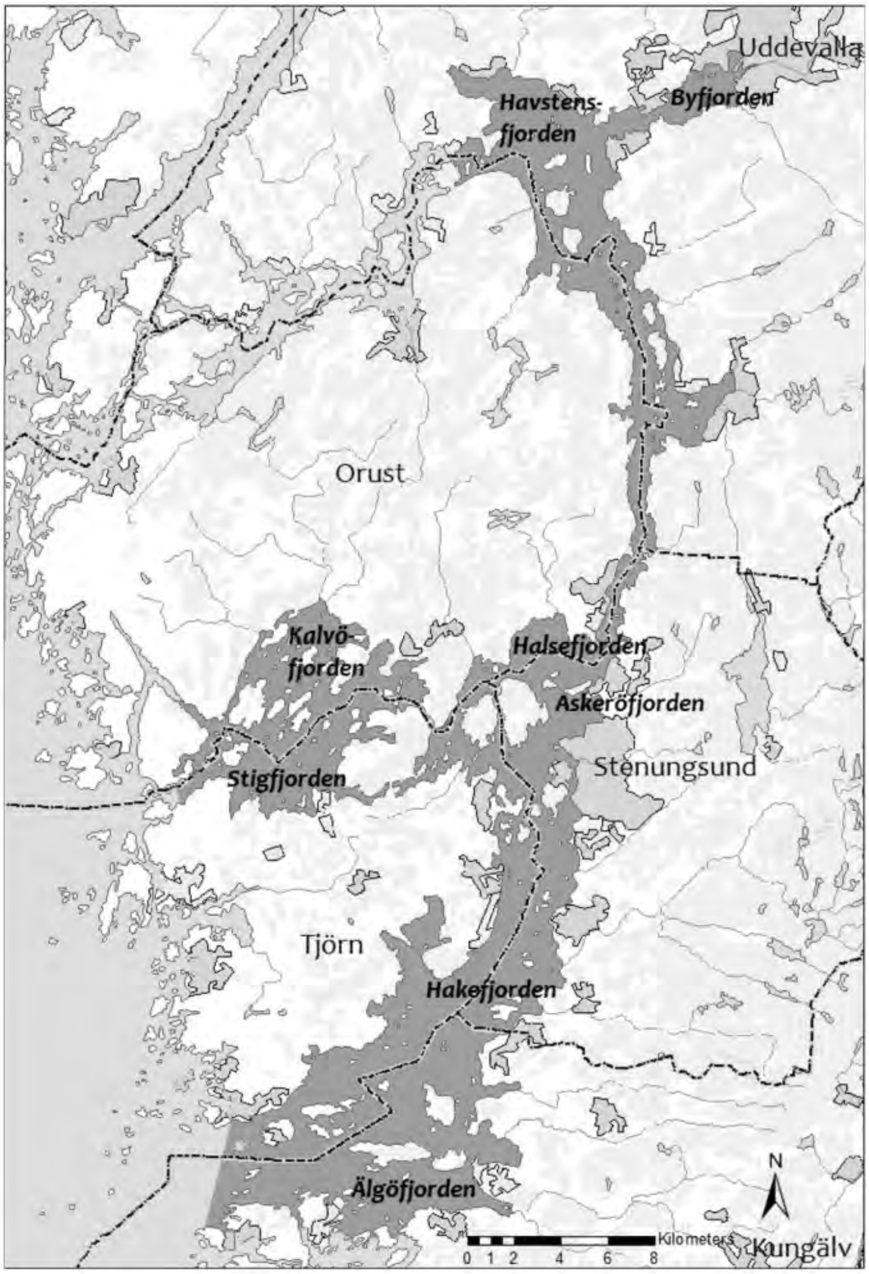

Figure 1. The original 8-fjords area (darker grey colour) inside or between the islands Tjörn and Orust. Dashed lines denote municipality borders. Background data from Lantmäteriet (open map data).

Moreover, epibenthos that feed on epiphytic algae on eelgrass serve as a food source for many fish species in different stages. Thus, the extent of eelgrass cover may in many ways be a limiting factor for the production of fish and for marine food production for humans (Baden *et al*., 2012). In addition, eelgrass meadows prevent sediment erosion or resuspension by waves and thereby allow storage of substantial amounts of carbon and nutrients (Cole and Moksnes, 2016). Between the 1980s and 2000, eelgrass cover decreased by about 60 percent in the Swedish Skagerrak area. Geographical variations were, however, substantial. Investigations in the 8-fjords have discerned a notable difference in eelgrass reduction between the three areas Stenungsund, Uddevalla, and Kungälv (Figure 4; Nyqvist *et al*., 2009). The cause of the reduction may have been a combination of eutrophication and trophic cascades following selective fishing of demersal fish such as cod. Such trophic cascades may have occurred in the Skagerrak around 1990 (Baden *et al*., 2012). The eelgrass meadows have not shown apparent signs of recovery, although an update of their state would benefit the analysis (Susanne Baden, pers. comm). Attempts have been made to artificially transplant eelgrass to depleted areas, albeit with limited success, possibly because trophic cascades resulting in low grazer abundance have not been reversed and turbid waters persist (SWaM, 2016; Niclas Åberg, pers. comm.).

The increasing numbers of harbour seals (*Phoca vitulina*) and great cormorants (*Phalacrocorax carbo sinensis*) have raised

Table 2. Changes in commercial fish catch between 1962 and 2004–2008 in Koljöfjorden, Havstensfjorden, Byfjorden, Halsefjorden, Askeröfjorden, Kalvöfjorden, Stigfjorden, and Hakefjorden.

Common name	Scientific name	1962 (tonnes/year)	2004–2008 (tonnes/year)	Percentual change
European lobster	*Homarus gammarus*	0.98	0.31	−69
Pollack	*Pollachius pollachius*	4.68	0.01	−100
Atlantic mackerel	*Scomber scombrus*	4.41	0.94	−79
Garfish	*Belone belone*	23.16	–	−100
Turbots	*Scophtalmus sp.*	1.10	–	−100
European plaice	*Pleuronectes platessa*	33.31	0.02	−100
Common dab	*Limanda limanda*	1.17	–	−100
Atlantic herring	*Clupea harengus*	16.83	203.13	+1107
European sprat	*Sprattus sprattus*	193.93	486.72	+151
European flounder	*Platichthys flesus*	8.53	–	−100
Atlantic cod	*Gadus morhua*	69.09	0.13	−100
Whiting	*Merlangius merlangus*	0.55	0.01	−98
Common sole	*Solea solea*	0.57	0.01	−99
Sea trout	*Salmo trutta*	2.35	0.01	−100

Data from Hannerz (1970) and the Swedish Board of Fisheries statistics (nowadays the Swedish Agency of Marine and Water Management).

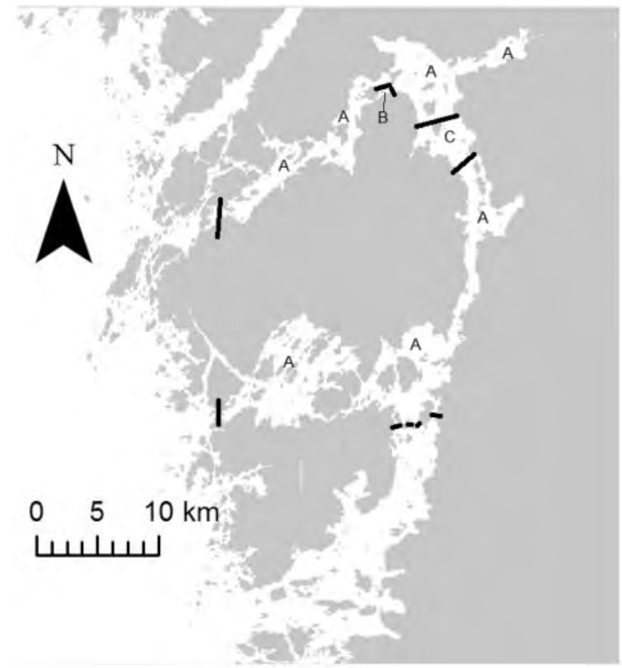

Figure 2. Fishing restrictions in the 8-fjord area. a: Fishing ban for cod, pollack and haddock. Fishing for other species with manual gear, crustacean pots and mussel scrapers are legal gears. b: All fishing is prohibited. c: Fishing with manual gear is allowed half of the year from Orust Island (see Figure 1) and the mainland. All other fishing is prohibited.

growing concern for potentially being additional threats to the recovery of demersal fish in the area. Seals and cormorants may even benefit from no-take zones and there are other examples in which top predators have been shown to prevent fish stock recovery (Boncoeur *et al.*, 2002; Fanshawe *et al.*, 2003; Middlemas *et al.*, 2006; Trzcinski *et al.*, 2006; O'Boyle and Sinclair, 2012; Bromaghin *et al.*, 2013). From having been extinct in Swedish waters in the early 1900s, great cormorant colonies re-established on the Swedish east coast in the mid-1900s and on the Swedish west coast in the 1990s where approximately 3000 breeding pairs were counted in 2012 (Engström and Wirdheim, 2014; Swedish Environmental Protection Agency, 2013). Harbour seals off the Swedish west coast have recovered after having been decimated by hunting, diseases and environmental toxins, with numbers increasing from about 3000 animals in the mid-1900s to historically high levels in the 2000s (Heide-Jørgensen and Härkönen, 1988; Olsen *et al.*, 2010). In the annual moult count, between 4000 and 6000 harbour seals have been counted in the Skagerrak during the last 5 years, with an annual increase of 7% (Bäcklin *et al.*, 2016). Preliminary investigations suggest that a similar development in abundance of seals and cormorants could also have occurred in the 8-fjords area (Karl Lundström and assistants, pers. obs.). However, the rise in top predator abundance which was recorded in the 2000s occurred after the decline in demersal fish in the 1970s. Thus, seals or cormorants are not a likely cause of the demersal fish decline.

Seal and cormorant hunting remains a controversial issue in Sweden and elsewhere. In the 8-fjords area, while some want hunting for harbour seals and great cormorants to be banned, there are also proponents of increased hunting. Included in the seal and cormorant controversy are the size and growth rate of the population as well as the diet of these predators. No systematic census or diet analysis has been performed in the 8-fjords area, so details about current numbers and prey choice of seals and cormorants in the area are lacking. However, the 8-fjords initiative has in cooperation with scientists performed a small-scale pilot study which showed that monitoring of abundance and diet of seals and cormorants in the area would indeed be possible. Further investigations of top predator abundance and diet could address whether seals or cormorants may prevent a recovery of demersal fish stocks. A conceptual Miradi model (Schwartz *et al.*, 2012) elaborating on how fishing and top predators may affect fish fauna and fish habitat is given in Figure 3.

In addition, the 8-fjords initiative has focused on a large number of other environmental and societal issues with more or less strong connections to fish communities and the coastal ecosystems, such as marine litter, nutrient inputs and eutrophication, other seabirds than cormorants, the distribution of blue mussel (*Mytilus edulis*) banks, artificial reef construction, mussel farming, tourism, recreational facilities, and trout (*Salmo trutta*) habitat restoration in the tributaries to the fjords (Johansson, 2015). The initiative has also been involved in artificial deepwater oxygenation of the By fjord which has been described in detail by Stigebrandt *et al.* (2015).

The 8-fjords initiative

Towards the end of the 1990s, an increasing number of people contacted the municipalities around the 8-fjords with concerns about the state of environment of the fjords. As mentioned, the primary concern was the depletion of fish stocks, in particular, of Atlantic cod. Discussions were initiated in 1999 about cooperation within the local communities which ended up in three working groups being formed: the fisheries group, the business group and the environmental group. The groups were coordinated by project leaders, who were eventually hired in 2008, and later on by a steering group (Figure 5). The fisheries group contains representatives for commercial fishermen, different organizations of recreational fishers, the County Administrative Board, and the SwAM, and this group primarily discusses fisheries issues. The business group consists of local entrepreneurs and discusses how better opportunities for nature and culture tourism could be created, and in addition, how crustaceans (e.g., mussels and lobsters) can be cultivated or caught. The environment group includes representatives of environmental organizations, organizations for recreational fishers, municipalities and the County Administrative Board and it has had a major focus on the nutrient loading to the fjords (Johansson, 2015).

The work of the 8-fjords initiative is ongoing, and new work depends on what is agreed between government agencies and other stakeholders. According to the project leader and the environmental advisor of the initiative, there has been a widespread acceptance of the no-take zone and other fishing restrictions and this is probably partly due to the great extent of stakeholder involvement. In addition, the initiative has put in place artificial reefs to promote lobster and fish aggregation, information campaigns have been launched, elvers (juvenile European eels; *Anguilla anguilla*) have been stocked, and various biotopes have been managed and protected, i.e. rather conventional conservation measures. The initiative has worked with decreasing the number of ghost-fishing nets and with opening up narrow straits in order to allow boat passage and increase the water circulation. Fishermen of various kinds have been encouraged to keep and report catch diaries. The lack of information about the effects of fish predation by seals and cormorants has been the focus of a pilot study for monitoring these predators. Spawning grounds for cod and blue mussel (*Mytilus edulis*) banks have been mapped, as

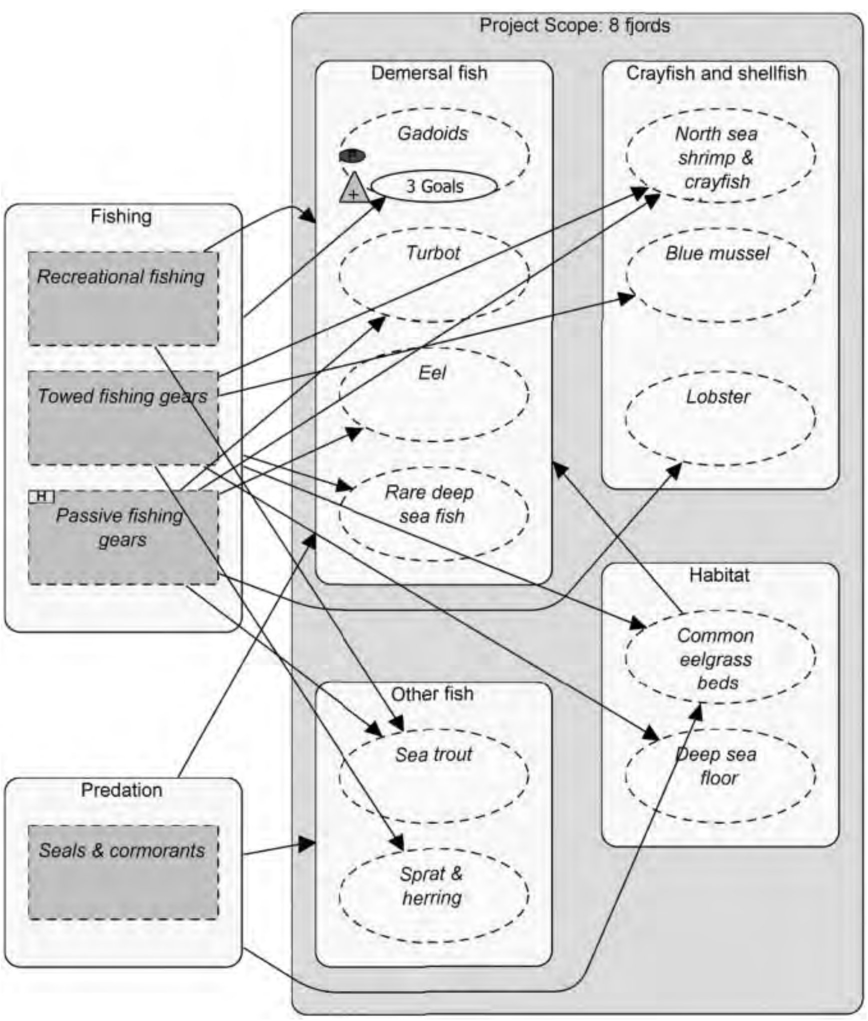

Figure 3. A Miradi model version 2.4.2. (Schwarz *et al.*, 2012) displaying the possible impact of fishing and top predators (seals and cormorants) on fish fauna and habitats. The diet and abundance of top predators has yet to be investigated.

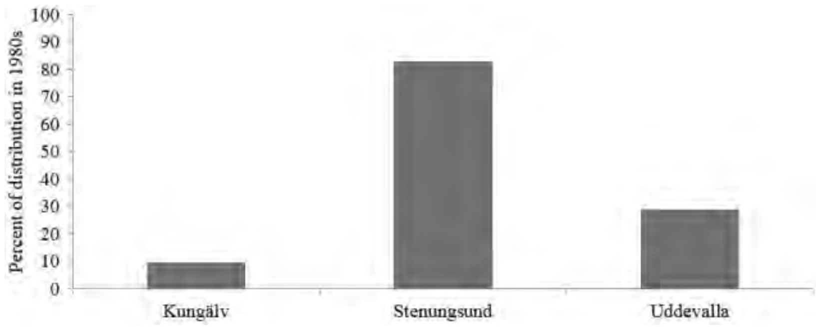

Figure 4. Distribution of eelgrass beds at monitoring stations in three areas of the 8-fjords in year 2000 compared to the 1980s. Data as mean values from Nyqvist *et al.* (2009).

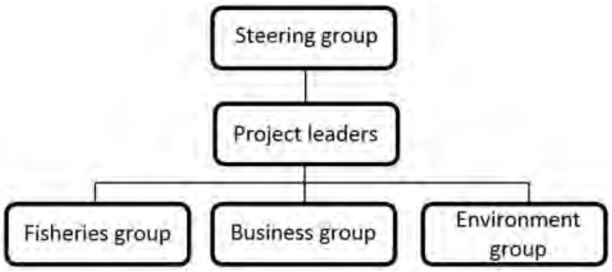

Figure 5. The structure of the 8-fjords initiative. Modified from Johansson (2015).

well as the distribution of the white-tailed eagle (*Haliaeetus albicilla*; Johansson, 2015).

Since 2008, there have been about 1–2 annual stakeholder meetings open to the general public with 100–200 participants per meeting. Meetings including smaller groups of stakeholders (e.g. recreational fishermen or business owners) have been held about once or twice per week. During both of these types of meetings, accomplishments have been discussed as well as how to proceed in collaboration with the management; e.g., how legal and financial constraints to desired changes should be handled. The management aims for the 8-fjords initiative have been the following (according to the project leader and the environmental advisor):

(1) get the piscivorous fish back,
(2) seas in balance,
(3) thriving coast and archipelago,
(4) a good sediment environment,
(5) extensive cooperation and co-management, and
(6) ecological and economic sustainability, including viable conditions for local business enterprises.

As earlier mentioned, this vision also includes recreating favourable conditions for eelgrass by means of points 1–6 above. However, there is no specific strategy relating to pollutants, seals or cormorants. In 2016, the fishing restrictions described above are being evaluated, and spawning habitats for trout in tributaries are continuously being improved, and these are currently the main task of the 8-fjords initiative.

How the EAF principles are addressed around the 8-fjords

To determine how the environmental work around the 8-fjords conforms to the EAF, the practical work will be compared to the 15 main EAF principles in Long *et al.* (2015), as described in the Introduction (Table 1).

Ecosystem connections (i) are largely considered; the 8-fjords initiative does not only work with fisheries, as has been described above, but also with nutrient loading and organic contaminants, and with eelgrass, mussel banks and other parts of the ecosystems, recognising that they are interconnected. The spatial management scale and its boundaries (iv, v) have resulted from the stakeholder initiative. The fjords inside the islands Tjörn and Orust form have many similarities in terms of ecology, but also in terms of traditions and societal aspects by being substantially affected by fishing, tourism and shipping. The managed waters are, however, slowly and in a controlled manner, expanding from the original 8-fjords area to additional fjords and other coastal waters (Figure 1). This is mainly occurring as an explicit wish from residents in nearby areas to be a part of the 8-fjords initiative, which has a reputation of being beneficial for local protection of coastal ecosystems in the area. Temporal scales and their boundaries (iv, v) are applied in various manners. The depletion of demersal fish stocks is not expected to change in the near future as it may take several decades for a recovery, given that the stocks will eventually recover. However, shorter timeframes may be applied when implementing various measures such as artificial reef constructions, nutrient abatement, beach cleaning, culling of seals and cormorants, or deciding about new fishing restrictions.

Decisions are taken based on scientific knowledge (x), as the initiative has tight cooperation with researchers from, e.g., the University of Gothenburg, the Swedish University of Agricultural Sciences, and the Royal Institute of Technology. These researchers come from various disciplines such as biology, oceanography, ecology, economics and sociology. Interdisciplinary (viii) and integrated management (vii) are also promoted. Östberg *et al.* (2010; 2012; 2013) are examples of interdisciplinary studies and have a large focus on environmental economics. Among the findings is that the willingness to pay for better water quality is greater than for stricter regulations concerning noise and litter (Östberg *et al.*, 2012). The coupling of social and ecological systems (ix) is acknowledged and highlighted by the initiative; e.g., the value of fishing for fishermen and society, and the value of well-functioning ecosystems for providing ecosystem services to society, including the local tourism industry, and the effects of various human pressures, such as fishing, agriculture and industrialization, on ecosystem functions.

Stakeholder involvement (xii) is a cornerstone of the 8-fjords initiative, and this involvement also improves the way in which decisions reflect the societal choice (xiii). By letting stakeholders participate in discussions and influence decision making, there has, as mentioned above, become a wide acceptance of fishing restrictions and other environmental measures. However, management decisions in terms of regulations are ultimately taken by SWaM while measures with fewer legal constraints such as restoration of spawning habitat for trout are undertaken by the 8-fjords initiative and its associated municipalities. Stakeholders and the general public are to a large degree concerned about the state of the fish stocks. Some are also very concerned about the number of seals which is perceived as much larger than before. Others worry more about marine litter, or about a possible dumping of sand and silt in the vicinities of eelgrass meadows. The dynamic nature (ii) and uncertainty (iii) of ecosystems are accounted for; for instance, the recovery of collapsed demersal fish stocks is acknowledged as being quite unpredictable even though extensive fishing restrictions have been implemented. Biodiversity and ecological integrity (xiv) are considered as important goals with management; although there seems to be particularly large concerns about demersal fish, sea trout, mussels, and eelgrass.

The principles adaptive management (vi) and suitable monitoring (xv) are addressed to a certain degree (see Discussion) because both are difficult to attain without a certain number of relevant indicators. There is widespread uneasiness among stakeholders regarding the scarcity of relevant data. There are some indicators regarding the 8-fjords that can be considered operational today, such as eelgrass cover in some areas, dissolved oxygen concentration, and catch in kilograms per trawling hour of cod, turbot, plaice, and whiting. Catch-per-unit-effort of eel in fyke nets in Stenungsund (ICES, 2016) is also an operational indicator. Catch-per-unit-effort of medium trophic level fish during 2012 is available from Bergström *et al.* (2016). Nutrient and chlorophyll concentrations are available from a nationwide database. There are, however, no operational economic and social indicators available. Implementing indicators that also include economic and social aspects as well as whole-ecosystem aspects, would advance these two principles to a greater degree. Moreover, those indicators that can be considered operational to some extent would benefit from more frequent monitoring.

Sustainability (xi) guides the work of the 8-fjords initiative considering that the aims of its work is to make sure that present human pressures do not jeopardise the needs of future generations. However, sustainability cannot be considered to prevail to a large degree because of the poor state of demersal fish stocks and the depleted state of eelgrass meadows. Management of the 8-fjords in the past did neither meet the needs of present generations nor those of future ones.

Discussion

This study shows that the 15 major EAF principles in Long *et al.* (2015) can be used to assess how the EAF is applied in practice in a case study. Although there are overlaps among certain principles, e.g., between principles iv (appropriate scales) and v (distinct boundaries), and between principles vi (adaptive management) and xv (appropriate monitoring), we still believe that it is suitable to consider all of these 15 principles because as a whole they provide a diverse, specified and fathomable picture of what the EAF is.

Moreover, it appears that the 8-fjords initiative has implemented EAF principles without being aware of it. Our findings can be useful for the 8-fjords initiative by highlighting the strengths and weaknesses of its work in an EAF perspective, which may guide its future work. In addition, this paper can attract increasing interest by researchers, managers, policymakers, and the general public to the work of the 8-fjords initiative. The findings do not however, imply that all or even most management goals regarding, e.g., demersal fish stock productivity and beneficial conditions for eelgrass meadows to recover have been reached. The EAF can be seen as an adaptive and robust management process which aims at continuous improvement (Cochrane, 2002). Thus, it is possible that additional measures will be necessary in order to strengthen demersal fish stocks and eelgrass meadows, or that managers and a wide range of stakeholders should be made aware of a possibly slow natural recovery process. The demersal fish depletion as indicated by Table 2 is conspicuous even in an international perspective and it is unclear if, how and when these stocks can recover (Svedäng 2003, Svedäng and Bardon, 2003, Thurstan and Roberts, 2010, Rose *et al.*, 2011; Bartolino *et al.*, 2012). By advancing the EAF principles, e.g., by introducing more useful indicators (Link, 2005; Methratta and Link, 2006; Fay *et al.*, 2013), it is possible that the demersal fish stocks and the eelgrass meadows may recover more rapidly and extensively, although this has yet to be demonstrated. Still, to the best of our knowledge, no previously published study on European waters has showed as extensive abidance by EAF principles as the 8-fjords initiative as described in this study. Examples which have been put forward (e.g., de Juan *et al.*, 2012; Gascuel *et al.*, 2012; Möllmann *et al.*, 2014) do not address all principles in Table 1. For instance, involvement of stakeholders is lacking or has not been described. Instead, these studies have provided modelling results and other important tools for the EAF. Nevertheless, the ambition to apply the EAF in all European Union waters is well-established in the Common Fisheries Policy (Anon, 2013; Ramírez-Monsalve *et al.*, 2016).

Southern Australia, including Tasmania (Fulton *et al.*, 2014) and the Galápagos Islands (Castrejón and Charles, 2013; Vinueza *et al.*, 2014) may be considered two of the first well-documented examples of the EAF in practice globally. These initiatives have been using a wide range of ecological, economic and social indicators, in contrast to the 8-fjords initiative, which only has some indicators and thereby a limited monitoring. New Zeeland applies a first step within the EAF, which includes single-species management of target species in fisheries, with bycatch and habitat factors taken into consideration (Cryer *et al.*, 2016). The EAF is applied on smaller scales in parts of Indonesia, the Philippines and Tanzania as well as on the Solomon Islands (Eriksson *et al.*, 2016). Substantial progress towards an EAF has also been made in Antarctic waters (Watters *et al.*, 2013), in the vicinity of the Benguela current outside southern Africa (Shannon *et al.*, 2010; Smith *et al.*, 2015) and in the northwest Atlantic (Link *et al.*, 2011). Other similar initiatives are on-going in many parts of the world (Pitcher *et al.*, 2009; Pomeroy *et al.*, 2015; see also other articles in this journal issue).

The continuous stakeholder involvement is the backbone of the EAF work around the 8-fjords. Knowledge on marine environmental issues is being strengthened and the experience of a wide range of inhabitants and visitors of the fjord is being shared, which is likely to improve the decision making. Moreover, by including stakeholders in discussions and by letting them influence decisions, it is likely that the acceptance has improved regarding fishing restrictions and other environmental measures. Burger and Niles (2013) found similar acceptance when stakeholders participated in all phases of a process leading to a beach at Brigantine, New Jersey being periodically closed for public access for environmental protection reasons. During the larger meetings 1–2 times per year, the "interested public" (cf. Soomai *et al.*, 2013) around the 8-fjords has probably been reached and may in turn have collected and shared information in their social networks regarding the state of the environment as well as environmental actions and other desired changes. It is essential to keep and develop the continuous network of stakeholders around the fjords to ensure that EAF principles are maintained (Mackinson *et al.*, 2011; Sandström *et al.*, 2015).

The main weakness of the management of the 8-fjords in relation to the principles in Table 1 is the scarcity of suitable key indicators for management of coastal ecosystems. Indicators are crucial in monitoring (xv) and adaptive management (vi; Schmitt and Osenberg, 1996; Ehler, 2003; Stelzenmüller *et al.*, 2013) and have been put forward as central (Link, 2005; Methratta and Link, 2006; Large *et al.*, 2013), and even necessary (Jennings, 2005; Fay *et al.*, 2013) for the EAF. Without ecological indicators, it is difficult to quantify human impacts on ecosystems (Methratta and Link, 2006; Leslie and McLeod, 2007), ecological trends and thresholds (Large *et al.*, 2013) as well as the the degree of progress towards reaching management goals (Link, 2005; Large *et al.*, 2013). Some key indicators for the impact of fisheries on ecosystems (see Link, 2005; Methratta and Link, 2006; Fay *et al.*, 2013) such as the biomass of functional groups of fish species are not available for the 8-fjords, although some other indicators have been mentioned in the previous section. Indicators that describe other important aspects of ecosystem structure and function, such as water transparency, nutrient and toxin loads and concentrations (Håkanson and Blenckner, 2008; Fleming-Lehtinen *et al.*, 2015; Lang *et al.*, 2015), are available to some extent. Economic and social indicators are wanted while being of comparable importance as ecological ones (Leslie and McLeod, 2007; Fulton *et al.*, 2014; Vinueza *et al.*, 2014). It is possible that relevant economic and social indicators are already extractable from statistics collected by the municipalities surrounding the fjords, and merit further investigations. Economic and social indicators could highlight the importance of reconstructed demersal fish stocks to inhabitants and tourists around the fjords and assign monetary values to the benefits that improved environmental conditions may bring. Moreover, it is desirable to establish additional ecological indicators, e.g., that more extensively describe variations in the fish community (Link, 2005; Methratta and Link, 2006), the extent of eelgrass cover (Carstensen *et al.*, 2016) or nitrogen isotopes in eelgrass (Schubert *et al.*, 2013), and the diet and abundance of seals and cormorants (Härkönen *et al.*, 2013; Conn *et al.*, 2013). Additional indicators should be developed in close cooperation between the 8-fjords initiative, responsible government agencies, and the research community.

A lack of data as well as of predictive ecological models should not be regarded as hindrances to applying the EAF (Patrick and Link, 2015). However, principles xv (appropriate monitoring) and vi (adaptive management) would be strengthened in the 8-fjords by bridging crucial knowledge gaps. For instance, identifying locally spawning demersal fish stocks in the fjords and mapping their habitats should be performed and provide the basis for future management measures. Studying the number and diet of seals and cormorants could determine the degree to which these top predators pose a threat to demersal fish stock recovery. Additional surveys of eelgrass can provide insights into recent development and how eelgrass recovery could be attained. What kind of ecosystem services are most important to residents and tourists should also be investigated, in addition to the range of goals that stakeholders have regarding the marine environmental work.

To conclude, the 8-fjords initiative and its achievements is in a social aspect a successful and locally popular example of EAF work in practice, although the ecosystems of the fjords, particularly demersal fish and eelgrass, are still in poor condition. This study has possibly demonstrated the first example of the EAF in practice in Europe and could therefore serve as an important contribution to EAF and stakeholder related science and management worldwide. Thus, although much remains to be done with respect to research and management goals, the 8-fjords initiative and what it has accomplished can provide useful guidelines towards practical implication of EAF principles in other parts of Europe and elsewhere.

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Contribution to the Themed Section: '*Case studies in operationalizing ecosystem-based management*'

Original Article

Tinkering with a tanker—slow evolution of a Swedish ecosystem approach

Henrik Österblom,[1,*] Jonas Hentati-Sundberg,[1,2] Nea Nevonen,[1] and Katarina Veem[3]

[1]*Stockholm Resilience Centre, Stockholm University, Stockholm, 106 91, Sweden*
[2]*Department of Aquatic Resources, Institute of Marine Research, Swedish University of Agricultural Sciences, Turistgatan 5, Lysekil 45330, Sweden*
[3]*Stockholm International Water Institute, Linnégatan 87 A, Stockholm, 100 55, Sweden*

**Corresponding author: tel: +46 73 707 88 16; e-mail: henrik.osterblom@su.se*

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The ecosystem approach is a salient policy paradigm originating from a scientific understanding of the reality of complex ecosystem dynamics. In this article, we investigate how Swedish national marine policies and practice between 2002 and 2015 have changed towards an ecosystem approach. Government documents, the scientific literature, institutional changes, changes in legislation, pilot projects, and changes in science and public opinion were reviewed and combined with information from expert interviews. We found that changes in policy and practice have slowly stimulated the development of an ecosystem approach, but that limited political leadership, challenges of coordination, different agency cultures, and limited learning appears to be key barriers for further and more substantial change. We compare and contrast the Swedish national process of change with other documented experiences of implementing an ecosystem approach and find that several countries struggle with similar challenges. Substantial work still remains in Sweden and we provide suggestions for how to stimulate further and more substantial change at the national level.

Keywords: Adaptive governance, fisheries management, marine resources, natural resource management, resilience, social-ecological system, sustainability science.

Introduction

A scientific paradigm shift is defined as a revolutionary change due to new and surprising insights (Kuhn, 1962). Shifts in policy can also be described at three hierarchical levels, where a first-order change includes continuous policy adaptations, a second-order change includes alterations of policy instruments without changing the underlying policy goals, and a third-order change (analogous to a paradigm shift) include a complete re-organization of the policy goals (Hall, 1993). Large-scale shifts in natural resource governance have been termed "transformations", which in many ways can be described as paradigm shifts (Olsson *et al.*, 2006). In such shifts, new visions and approaches have changed the way in which people relate to ecosystems and how stakeholders interact.

A shift to an ecosystem approach to marine resource management has been described as a paradigm shift (Browman and Stergiou, 2005), from a traditional, top-down and sector-based approach, to a multilevel, cross-sectoral, and integrated approach (McLeod and Leslie, 2009; Tallis *et al.*, 2010; Berkes, 2012; Engler, 2015). The demand for this shift is resulting from a growing recognition that sector based, "command and control" management (Holling and Meffe, 1996) is insufficient and that science, policy and practice need to co-develop approaches to address messy and "wicked" environmental problems (Jentoft and Chuenpagdee, 2009; Berkes, 2012). However, despite a broad recognition of the necessity for an ecosystem approach (Browman and Stergiou, 2005; Engler, 2015), establishing marine zoning and other forms of governance that require coordination across sectors is often constrained by inflexible institutions, unclear rules and responsibilities, power dynamics, lack of public support, insufficient legislation and limited learning (Leslie and McLeod, 2007; Kittinger *et al.*, 2011; Richter *et al.*, 2015).

In this review, we describe how the ecosystem approach has developed in Sweden between 2002 and 2015. We used government documents and scientific reports, reviewed changes in relevant institutions, legislation, and public opinion, and studied pilot projects. We also carried out eighteen interviews with politicians, parliamentarians and experts with present or previous employment in relevant agencies and ministries, including in the Swedish parliament and government office (six interview), the Environmental Protection Agency (EPA, six interviews), and the Swedish Agency for Marine and Water Management (SWaM, six interviews). Three of the latter had previously worked at the National Board of Fisheries (NBoF).

The starting point for this study is the "Commission on the Marine Environment", (CME) established by the Swedish Government in 2002 (Figure 1) and tasked to work for nine months to propose measures for major policy change, based on an ecosystem approach. The Minister of Environment at the time wanted to make the marine environment a political priority:

> "*In the coming years the most important issue in our surroundings will be the marine environment. My ambition is that the commission lays the foundation necessary to lift up marine environmental issues*" (SOU, 2003).

First, we describe how CME proposals have been associated with tangible outcomes in policy and practice. Then, we compare these developments to other experiences with operationalizing an ecosystem approach, specifically in relation to a number of "consensus elements" or "key principles" of the ecosystem approach (Engler, 2015; Long *et al.*, 2015) and case studies describing the process of change towards more integrated and ecosystem-based management approaches (e.g. Schultz *et al.*, 2015). Finally, we discuss whether observed changes can be described as a paradigm shift, and provide suggestions for how further change could be stimulated.

Development of a Swedish ecosystem approach (2002–2015)

Swedish Government Official Reports ("Statens Offentliga Utredningar", or SOU), such as the one prepared by CME, provide a mechanism for expert input and external policy advice for the government. Policy makers are not bound by these recommendations, but act on them if they align with political priorities. All suggestions for policy change are negotiated within the government offices, including all the ministries concerned, and the parliament, which inherently leads to trade-offs between multiple political priorities. A Minister of Environment, for instance, will thus act on recommendations published in a Government Official Report to the extent he or she is willing and able to do so. When significant recommendations are operationalized, a Government bill ("Proposition") is prepared and made into law or regulation through adoption in the parliament.

The CME proposals aimed at both integrating across sectors, and improving the environmental performance of individual sectors (e.g. fisheries or agriculture). Here, we focus on the integrated and area-based aspects of the ecosystem approach, rather than progress in individual sectors, see (Engler, 2015). The main proposals focused on (i) improving government agency leadership and coordination, (ii) developing a national marine strategy, with a particular focus on inclusive spatial planning, (iii) increasingly using adaptive management, (iv) stimulating public awareness, and (v) improving the multidisciplinary scientific

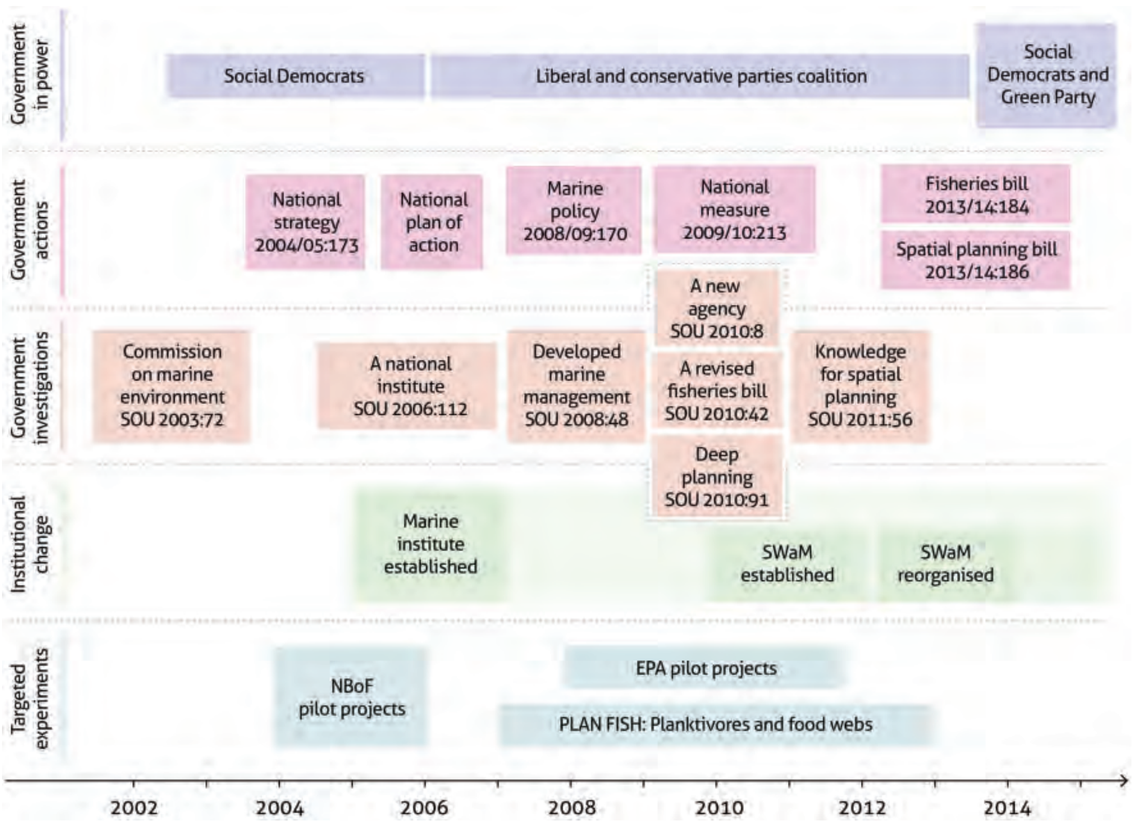

Figure 1. Summary of key Swedish marine policy and practice developments.

basis and creating a stronger link between science and policy (Supplementary Table S1). We describe how additional investigations, policy- and action plans, policy and legal change, reorganization of government agencies, and the scientific community developed along the lines of these proposals.

Establishing leadership and improving coordination across sectors

CME identified the lack of a designated lead agency and lack of coordination across sectors as a key barrier for implementing the ecosystem approach. To overcome this barrier, the CME recommended that the EPA should be given an overarching responsibility for the marine environment (Supplementary Table S1). However, the subsequent Government Official Report *Developed Management of the Marine Environment* (*SOU 2008:48*, Supplementary Table S2) concluded that the EPA did not cover all necessary aspects to legitimately act as the central agency. The Government Official Report *An Agency for Water and Marine Management* (*SOU 2010:8*, Supplementary Table S2) and the Government bill *Investigation Regarding Establishment of a New Agency for Marine and Water Management* (Anonymous, 2010) described how a new agency would incorporate all relevant responsibilities carried out by the EPA and merge them with the NBoF.

A new national agency, SWaM, with a broad mandate to manage marine and freshwater issues (including spatial planning) was established in June 2011 (Figure 1 and Supplementary Table S2). The purpose was to improve and strengthen marine management thorough a holistic and comprehensive agency for all water and marine issues.

Despite the Government's ambitions to integrate across sectors; however, freshwater management was not integrated with marine management when SWaM was established. Freshwater management in Sweden is guided by the implementation of the European Water Framework directive (2000/60/EG) (Anonymous, 2000). In 2004, the operationalizing of the directive resulted in the adoption of national regulation 2004:660 (Anonymous, 2004) and the establishment of five regional water agencies. When SWaM was established in 2011, they were tasked with coordination and development of the management of freshwater resources, carried out by the five regional water agencies. Our interviews suggest that these regional agencies are perceived as unable to deliver the active local and regional management that was intended. Instead, regional interest groups have influenced priorities and their effectiveness is being reviewed.

Marine policy is also guided by Sweden's environmental quality objectives (Government bill 2000/01:130, 2004/05:150, and 2009/10:155) which cover all areas of environmental policy—from unpolluted air, lakes free from eutrophication and acidification, to functioning forest and farmland ecosystems. For each objective there are a number of specifications, clarifying the desired state of the environment which is to be attained (EPA, 2012). The desired state has to be achieved within one generation (the generational goal) and all environmental policy should be directed towards ensuring that (EPA, 2012). EPA coordinates these policies, but the responsibility for freshwater and marine resource management was transferred to the regional water agencies and SWaM respectively, and then reported to EPA.

In response to the operationalizing of the government bills on environmental quality objectives in 2004–2011, the EPA developed substantial competence in the field of marine resource management. With the establishment of SWaM, these responsibilities were transferred from Stockholm, on the East Coast of Sweden, to the new agency in Gothenburg, on the West Coast. The move was carefully prepared with written documentation of each policy area, as very few staff members were willing to make the move.

The new agency was established together with the NBoF. The NBoF had, for decades, worked closely with and supported the fishing industry (Ask *et al.*, 2015), which resulted in frequent and heated conflicts with both EPA and environmental non-governmental organizations (NGOs). The last Director General of the NBoF (2005–2011) had made a concerted effort to "green the culture" of the agency. However, the interviews all describe it as a major challenge to bring cohesion to the new agency where the NBoF culture "was infused in the walls" and "resisted" the new and holistic ecosystem-based approach (e.g. regarding fish as part of a greater ecosystem rather than just as a commodity). Moreover, interviewees expressed frustration with SWaM for lack of experience with relevant topics and inability to deliver with adequate quality.

SWaM was thus forced to operate in a fragmented institutional landscape, and was influenced by substantial loss of institutional memory and conflicting agency cultures. According to our interviews, the agency was perceived as unable to provide the necessary leadership and its perceived inefficiency was a conversation piece among external stakeholders, both public and private. The agency underwent a major reorganization in 2013 aimed to address some of these challenges (although internal documentation of SWaM did not specifically highlight that cultural differences represented a challenge).

Given the strong emphasis on different agency cultures in our interviews, and the history of conflict and tension between different agencies and actors, we found it surprising to note that the preparatory work for proposing the establishment of SWaM [*An Agency for Water and Marine Management* (*SOU 2010:8*), see Supplementary Table S2], primarily focused on cost effectiveness and administrative advantages, and that it did not address cultural differences between NBoF and EPA.

Developing a system of inclusive spatial planning

Establishing a system of spatial plans was perceived by CME as a main tool to go from piecemeal and reactive management, to an integrated and proactive approach (Supplementary Table S1). Spatial planning has received substantial attention in subsequent government activities, including in the National Strategy from 2004 (Figure 1), but most significantly through the Government Official Report *Developed Management of the Marine Environment* (*SOU 2008:48)* (conducted between 2006 and 2008, Figure 1), the bill *A Congruent Marine Policy for Sweden 2008/09:170* (presented in 2009, Figure 1), the Government Official Report *Deep Planning—Physical Mapping of the Sea (SOU 2010:91)* (conducted between 2009 and 2010) and the spatial planning bill *Householding Marine Areas 2013/14:186* (presented to and passed by Parliament in 2014, Figure 1, see also Supplementary Table S2).

Spatial planning of the marine environment hardly existed in Sweden prior to 2002 but is becoming a national priority for the government and its agencies (SWaM, 2012, 2015). The adoption of a legal framework has made the development of spatial plans for three major areas of the Swedish economic zone possible and will be presented to the government in 2019. It has been a long process and the links to other relevant legislation have been thoroughly addressed. SWaM receives a clear mandate and responsibility in implementation and coordination. There is, however a lack of clear directives in case of conflict or dissenting views between the central agency and local or regional authorities, which may prove to be problematic. It therefore remains to be seen whether spatial planning will become an inclusive and effective tool for improving ecosystem integrity and sustainability, or whether it will primarily represent a planning tool for area-based marine activities.

Learning by doing: adaptive management

The CME emphasized the importance of adaptive management and here, we identify a number of relevant initiatives that has taken place during the time period (Table 1 and Supplementary Table S3), all to various extent, designed to learn from, and evaluate practical experience with ecosystem-based management approaches. For instance, the NBoF initiated and co-ordinated six pilot projects in 2004 of local fisheries co-management, designed to test and evaluate how this management approach could complement existing approaches (Figure 1). An evaluation of this initiative in 2006 (when it was formally discontinued) illustrated that users actively engaged in adaptive and learning based approaches, and by doing so, were able to developed shared visions and novel forms of collaboration. They were also able to better mitigate conflicts and agree on measures to address perceived problems (NBoF, 2007). One of these co-management initiatives (designed to balance impacts from small-scale Northern shrimp *Pandalus borealis* trawling with consideration to highly vulnerable cold water corals) has been institutionalized through the establishment of the first Swedish marine national park in 2009. The NBoF proposed to institutionalize fisheries co-management as a general method for managing Swedish coastal fisheries (NBoF, 2007), but this proposal has not led to any action by the government.

In 2008, the Swedish EPA analogously initiated five pilot projects (Figure 1, Supplementary Table S3) tasked to develop collaborative and multiple stakeholder-based local and adaptive management plans (EPA, 2011). These pilot projects were discontinued in 2011 but a formal evaluation (Norrby *et al.*, 2011) and scientific studies (Sandström *et al.*, 2014, 2015; Bodin *et al.*, 2016)

Table 1. Getting the ingredients right. How does 8 "consensus elements" and 15 "key principles" of the ecosystem approach compare to Swedish observations?

Eight consensus elements (Engler, 2015)	Fifteen key principles (Long et al., 2015)	The Swedish equivalent
Ecosystem approach is a holistic, or system, approach	Consider Ecosystem Connections Integrated management	Holistic and system-based approaches in science, policy and practice are emerging, but are still in an early stage of development.
Humans are part of nature	Recognize coupled social-ecological systems	Policies generally tended to treat humans as an external disturbance to the marine environment, rather than as an integrated part
Place-based management with ecologically defined boundaries	Distinct boundaries	Current focus on marine spatial planning will put a strong focus on place-based management. Local experiences of co-management can contribute with important knowledge
Management should be decentralized to the lowest appropriate level	Appropriate spatial and temporal scales	Swedish municipalities have a strong mandate to develop their own policies, guided by national policies
Management should be based on collaborative decision making	Stakeholder involvement Decisions reflect societal choice	Most of the development 2002–2015 has been top-down and expert driven, coupled to national consultations of policy development and co-management
Management should focus on the long term	Sustainability Ecological integrity and biodiversity	Sweden operates under a system of 16 environmental quality objectives http://www.miljomal.se/sv/Environmental-Objectives-Portal/, with specific targets for the marine environment, eutrophication, biodiversity, toxic pollutants, etc. They should guide all policies in all sectors and be fulfilled by 2020.
Ecosystem approach is knowledge based	Use of scientific knowledge Interdisciplinary	Substantial national and international funding has been devoted to increase the knowledge base for the marine environment. Most scientific efforts are however undertaken within specific disciplines.
Dealing with uncertainty: precautionary approach and adaptive management	Adaptive management Accounting for dynamic nature of ecosystems Appropriate monitoring Acknowledge uncertainty	A number of attempts to use adaptive management have been carried out at smaller geographical scales. Adaptive management, which explicitly embraces uncertainty and coupled to appropriate monitoring, is still limited.

highlighted that important social capital and learning were developed in all areas. However, given the long time it takes to establish collaboration between diverse interests, it appears as if the short time period during which the pilot projects were in operation was insufficient (Sandström *et al.*, 2014). For instance, measures implemented by the EPA previously in these regions, but without stakeholder involvement and perceived as having limited legitimacy, had generated mistrust that took time to overcome. Unclear instructions from the EPA and uncertainty about the purpose of the pilot projects also delayed action. However, large personal commitment from project leaders, stand out as a key factor for making progress, as were previous experiences in organization around similar issues (Ö. Bodin, pers. comm.).

Scientific experiments can also help developing practical experiences with adaptive management and the ecosystem approach (Österblom *et al.*, 2016). A science-based adaptive management experiment, focusing on nutrient mitigation strategies coupled to a major nutrient reduction plant, illustrates the importance of collaborative learning between scientists and practitioners (Franzén *et al.*, 2011). Philanthropy-funded biomanipulation initiatives to reduce eutrophication (Elmgren *et al.*, 2012) or improve water quality through the introduction of predatory fish, i.e. pikeperch *Sander lucioperca* to trigger a trophic cascade (Hansson, 2013) represent notable examples where management measures have been designed as closely monitored experiments. Research and testing of measures to bind phosphorous in sediments by applying aluminium appear promising for improving water quality, but the introduction of predatory fish has not generated any measurable effects (Hansson, 2013).

The Swedish government also led an ambitious and long-term (7 years) ecological adaptive management experiment called "PLAN-FISH" (Planktivore management – linking food web dynamics to fisheries in the Baltic Sea) in order to investigate the strength of trophic cascading effects (Figure 1). The project investigated whether targeted fisheries for sprat *Sprattus sprattus* could be used as a method for improving the prospects for the recovery of cod *Gadus morhua* and other predatory fish in the ecosystem (scientific studies had indicated that a large sprat stock would e.g. compete with larval cod for food). The project developed important insights in relation to the seasonal strength of top-down, versus bottom-up trophic cascades, as well as possible threshold levels above which the sprat stock would have negative effects on cod. These findings improved the prospects for understanding how targeted fishing could improve the recovery of depleted species and is currently processed in order to be further developed in to scientific advice when setting fishing quotas (Appelberg *et al.*, 2013).

These examples illustrate that experiments with adaptive management provide important insights and stimulate an understanding of how to implement an ecosystem approach, while also highlighting challenges, including the importance of developing a long-term commitment from policy makers and funders, and the complexity of ecosystems.

Public awareness

CME underlined the importance of public awareness campaigns (Supplementary Table S1). The frequency and intensity of the national public debate increased substantially following a suggested cod-fishing moratorium in 2002, which became headline news and contributed to widespread public awareness, resulting in changes in consumer behaviour (partially spurred by a consumer guide developed by the World Wide Fund For Nature, WWF) (Crona *et al.*, 2015). Re-occurring events of cyanobacterial blooms during the peak of summer vacations have further contributed to environmental awareness as they are frequently the subject of summer time newspaper headlines, combined with TV documentaries and regularly reoccurring NGO campaigns.

Swedish public opinion has been measured on an annual basis by the Society Opinion Media institute http://som.gu.se/som_institute. In 2013, a deteriorating marine environment was ranked second, after environmental degradation, but ahead of e.g. organized crime, increased xenophobia and high unemployment, as major concerns for Swedish citizens (Bergström and Oscarsson, 2014; Ekengren Oscarson and Bergström, 2014). The public in all Baltic Sea countries are aware of (and concerned with) the challenges in the Baltic Sea and the willingness to pay for an improved marine environment significantly exceeds the estimated costs of action (BalticSTERN, 2013). Judged by this high level of public awareness and interest, there appears to be a large interest for substantial investments to improve the marine environment.

Bridging multidisciplinary science and policy

CME emphasized that cross-sectoral and interdisciplinary science represented an important support for decision makers. Swedish marine ecosystem scientists were pioneers in integrated analyses of ecosystem dynamics and linkages between the ecosystem, economics and social changes (Hammer *et al.*, 1993; Holmlund and Hammer, 1999; Jansson and Dahlberg, 1999). This work triggered wide scientific discussion, but the governance model in operation at that time, was arguably designed in a way that made cross-sectoral planning and decision-making difficult. A second wave of research triggered a renewed discussion on resilience, ecosystem change, ecological cascading effects and regime shifts (Österblom *et al.*, 2007; Casini *et al.*, 2008, 2009).

The Government Official Report *A Swedish Marine Institute* (*SOU 2006: 112)* (Figure 1, Supplementary Table S2) proposed improving the performance of four regional research institutes (three of which were established already in 1989), under the umbrella of one national marine institute. The merger was expected to address a number of deficiencies in coordination and collaboration, improve the scientific support for design and evaluation of environmental monitoring, as well as contribute to multidisciplinary scientific syntheses and evaluations, which would support relevant agencies.

Consequently, the Marine Institute (HMI) was established in 2008 (in Gothenburg) but an evaluation of its activities between 2008 and 2012 concluded that coordination had not worked well and that cooperation had been limited (Statskontoret, 2013). The merger resulted in duplication of efforts and inefficient use of resources (Statskontoret, 2013). Competition between participating universities, insufficient governance mechanisms, strong internal cultures and insufficient (economic) incentives were all identified as reasons for the limited cooperation. (Statskontoret, 2013).

The marine science centre at Stockholm University was one of the four research institutes connected to HMI. In 2013, Stockholm university established a multidisciplinary Baltic Sea Centre, with a similar focus to that of HMI. The evaluation of HMI (Statskontoret, 2013) concluded that although this centre represents an important addition of resources, its establishment also risk contributing to additional competition between HMI and Stockholm.

Swedish national funding agencies are supporting multidisciplinary research programmes, such as the BONUS programme, designed to stimulate international and multidisciplinary marine science in the Baltic Sea (Kononen *et al.*, 2014), and existing integrated marine ecosystem assessments, models and indicators are advanced (Diekmann and Möllmann, 2010; Möllmann *et al.*, 2013; Meier *et al.*, 2014; Wulff *et al.*, 2014; Lade *et al.*, 2015; Undeman *et al.*, 2015). These multidisciplinary efforts improve the prospects for better coordination and interaction between science and policy, since they can stimulate collaboration between academics and provide the ecosystem-level type of advice that decision makers are looking for. However, the future development of such activities, e.g. through collaboration between HMI and the Baltic Sea Centre (located at two of the largest universities and on the west and east coasts respectively), depends critically on how turf wars are addressed, how funding is distributed and how collaborative projects are co-conceived.

Why has the Swedish process of change been so slow?

Our review and interviews suggests that the national process of change towards a more holistic, adaptive, and ecosystem-based management approach has been moving along at a steady but slow speed. It has been argued that sectorial implementation of the ecosystem approach should be evolutionary (Cowan *et al.*, 2012), whereas operationalization of the type of cross-sectoral and area-based management considered here, which requires substantial institutional and legal change, should rather be revolutionary (Berkes, 2012; Engler, 2015). Our review and comparison with identified "consensus elements" or "key elements" of the ecosystem approach (Table 1) indicates that progress has been made, but that changes are evolutionary rather than revolutionary. They resemble the minor adjustment of the course of a tanker, steadily moving along the same trajectory, but with substantial path dependency (Boonstra and de Boer, 2014). The extent to which recent adjustments influence the present course is unclear, as is when or how it will influence the "final" destination.

A recent synthesis of three case studies of adaptive and ecosystem-based management (Schultz *et al.*, 2015) illustrates a common pattern of development over time. Specifically, that: (i) policy entrepreneurs have been able to reframe the perception of the ecosystem in question and create new "umbrella concepts" that served as a common vision for action, that (ii) bridging organizations could channel resources, mobilize knowledge and connect sectors and scales and that c) a crisis (of some form) contributed substantially to triggering change (Schultz *et al.*, 2015). Adaptive management initiatives can however not only be guided by dynamics and processes from the bottom-up, but need to be adequately supported and framed by enabling legislation and appropriate institutions (Olsson *et al.*, 2002), developed from the top-down. Such development requires political leadership.

Political leadership

The political leadership has changed twice during the study period, from a Social Democratic Party-led government in 2002, to a coalition of liberal and conservative parties in 2006, and a coalition of Social Democrats and the Green Party in 2014 (Figure 1). Starting from 2007, the Swedish government allocated additional resources to stimulate measures that were anticipated to be particularly effective to achieve the national marine environmental quality objectives (Regeringen, 2011; OECD, 2015). A recent evaluation of the effect of these and other measures however, could not identify any progress towards reaching the environmental quality objectives. In fact, there were no positive trends for either objective 4: A non-Toxic Environment, objective 7: Zero Eutrophication, or objective 10: A balanced Marine Environment, Flouring Coastal Areas and Archipelagos—the three key environmental objectives for the marine environment. The evaluation concluded that none of these objectives will be met by 2020 (EPA, 2015).

Our interviews indicated a wavering level of ambition among central agencies and inconsistent political will in the government office to enable more comprehensive change. Although a number of political actions aimed to improve the marine environment have been initiated during the time period, key Ministers have been unable, or unwilling, to make the marine environment a main, long-term, priority. Strong political leadership has thus been lacking. The Swedish Society for Nature Conservation (a major national environmental NGO) studied the environmental policy promises made by parties in the parliament before the election 2010 and after 4 years in office 2014. The period, which was followed by another 4-year period with a conservative government, was labelled "Four lost years for the environment" and was characterized by loss of tempo, delays and changes in priorities (SSNC, 2014).

Potentially as a consequence of this, we also found discrepancies between expert-based advice and subsequent political decisions. The Government Report *Developed Management of the Marine Environment* (Figure 1), for instance, included recommendations for legally binding spatial plans and protection of biological diversity, whereas the bill *Householding Marine Areas* (Figure 1) included non-binding plans and a more utilitarian approach (Supplementary Table S2), consistent with priorities of the government in office at the time. A utilitarian approach is also prevalent in the "Blue Growth" concept, which is increasingly advocated for by national and international government agencies and among NGOs (COM, 2014; WWF, 2015).

Preceding the election in 2010, social-democratic Governments had been in power since 1994. During this period, the environment was a clear and strong policy focus under the umbrella of "building the green welfare state", which gained popular approval. Global financial crisis and related national economic challenges reduced the interest for this focus as elections approached in 2010. The shifts in government and resulting fragmentation of decisions pertinent for coherent, integrated marine management have weakened the implementation and underlying intentions. An emphasis on jobs and growth, together with limited progress in reaching environmental goals, raise important concerns related to how sustainability of ecosystems are considered and integrated in practical policies. Similar limitations have also been observed for the implementation of the Australian Oceans Policy, where the complexity of issues, inadequate legislation and funding, and limited ownership of the policy process substantially limited the scope from original intents, e.g. when implementing spatial planning (Vince *et al.*, 2015)

Non-state actors as policy entrepreneurs?

Non-state actors have mobilized capacity to compensate for the perceived limited political leadership and are demanding more action, but there is limited coordination between such actors. Individual annual campaigns, evaluations of policy measures, and collaborative scenarios (WWF, 2010; SSNC, 2014) are common products from such NGOs.

Two philanthropic foundations, BalticSea2020, established in 2006, and Zennström Philanthropies, established in 2007, where new organizations during this time period. BalticSea2020 focuses on improving the environmental condition of the Baltic Sea, using a private donation of 500 million SEK (50–60 million €) and intends to only be in operation during a limited time period (until 2020). The foundation has funded policy campaigns, television films and research projects (e.g. on biomanipulation). Zennström Philanthropies carried out campaigns, trying to fill the space not already claimed by existing, established NGOs. Today they work exclusively with a programme focusing on supporting local governments in their efforts to improve the Baltic Sea.

It seems that even with significant funding, neither the old or newer NGOs has been able to operate as a policy entrepreneur and stimulate transformative change (Schultz *et al.*, 2015) on a large scale, partly perhaps because, umbrella concepts that integrate social innovation, social movements, socio-technical transitions, and ecosystem stewardship (Olsson *et al.*, 2006, 2014) have not been used or integrated in their activities. Limited coordination of efforts may also affect their ability to influence change.

Challenges with establishing bridging organizations

Legal and institutional change have been demonstrated as important for removing formal barriers for coordination across sectors in the United States (Gunderson *et al.*, 1995), but e.g. different agency cultures or management styles, and informal power dynamics, can also represent important barriers (Kittinger *et al.* 2011). It takes time to become a credible coordinator and Swedish efforts to establish bridging organizations that support a transition towards more integrated management have not been successful. Neither SWaM, nor HMI, has yet been able to fill this role, nor any of the NGOs.

Recent geographical shifts in balance and power of scientific institutions and agencies have changed the conditions for different actors to engage in formal and informal dialogues between science and policy. Reorganization of scientific networks (Misund and Skjoldal, 2005; Stange *et al.*, 2012) or government agencies elsewhere (Kittinger *et al.*, 2011; Vince *et al.*, 2015) illustrates similar challenges with turf wars, a lack of legitimacy and losses in institutional memory and capacity to those experienced in Sweden. Strategies and targeted efforts for mitigating barriers between powerful and potentially competing scientific institutions, or between old and new agencies, could improve institutional and collaborative learning (Kittinger *et al.*, 2011). Co-development of priorities, and repeated exchange of knowledge and experiences (mentoring) between different scientific institutions and between the EPA and SWaM could be part of a strategy for improving collaboration and ensuring that institutional memory is valued and developed. Simple measures, such as more equal distribution of funding between HMI and participating institutions, would likely have improved scientific collaboration (Statskontoret, 2013).

The location of both SWaM and HMI on the Swedish west coast, away from the national centre of political power on the East Coast is analogous to the National Oceans Office Agency (NOO) in Australia, established to increase integration across sectors and facilitate implementation of the National Oceans Policy. NOO was located in Hobart, far from other key agencies in Canberra, which had adverse effects on its operations and eventually led to the loss of its executive agency status (Vince *et al.*, 2015). Geographic co-location of relevant agencies appears to be a necessary, but not in itself, sufficient condition for the development of ecosystem-based management.

Using crises as opportunities

The status of the marine environment along the Swedish coasts is frequently highlighted as a major crisis in Swedish media and in reports from NGOs. Regular reports of anoxic sediments and depleted fish stocks have increased public awareness, but also likely contributed to policy fatigue. Limited ecological recovery potential (Österblom *et al.*, 2007; Savchuk and Wulff, 2009; Blenckner *et al.*, 2015) suggest that effects of (expensive) actions taken today may not be evident for decades, which may limit political will to invest substantially in the marine environment. However, crises that stimulate a transition to an ecosystem approach may not necessarily originate from the same geographical scale or even from the same policy area. Both ecological crisis (Olsson *et al.*, 2008) and shifts in political power (Gelcich *et al.*, 2010), can be important for "the opening of an opportunity" for change, provided that individual agents and policy entrepreneurs can skilfully "navigate the transition" (Folke *et al.*, 2005). In the Swedish example, it is currently unclear whether or not such entrepreneurs exist, and/or whether crises associated with eutrophication or overfishing have been perceived as sufficiently serious to open up an opportunity for change.

Moving beyond tinkering

Marine spatial planning is emerging as an important tool around the world, but the original focus on ecosystems is often lost along the way as the tool is implemented (Merrie and Olsson, 2014). As Sweden applies spatial planning, ecosystem sustainability and environmental quality objectives should represent the foundation for decisions taken. It is also important to engage with the most recent thinking on adaptive and dynamic oceans management (Maxwell *et al.*, 2015; Dunn *et al.*, 2016), which could stimulate interesting technological developments for real-time management and novel collaboration between government agencies, scientists, policy entrepreneurs, technology firms, and financial actors.

The Swedish experiences with pilot projects to investigate the potential for adaptive management illustrate that important insights can be harvested from such social-ecological innovations (Olsson and Galaz, 2012). The relatively short time period during which these initiatives were operational, however, appear ill suited for the long-term processes associated with establishing trust and enabling change. Without formal (scientific) evaluation and synthesis of such pilot projects, important insights and social learning will be lost (Leslie and McLeod, 2007; Berkes, 2012). Adequate funding for associating such projects with science-based, monitoring and evaluation (of both social and ecological dynamics), in turn, could lay the foundation for novel and long-term investments to scale up and further develop ecosystem-based management initiatives.

The scientific literature is becoming increasingly clear with what the ecosystem approach can and should mean in practice (Curtin and Prellezo, 2010; Kittinger *et al.*, 2014; Engler, 2015; Long *et al.*, 2015; Richter *et al.*, 2015). Diverse empirical insights of how interconnected social-ecological systems represent challenges and opportunities for implementing an ecosystem approach are rapidly accumulating (Murawski, 2007; Ruckelshaus *et al.*, 2008; Österblom *et al.*, 2010; Tallis *et al.*, 2010; Leslie *et al.*, 2015). Similar approaches for implementing the ecosystem approach in Australia, Canada, Norway (Sainsbury *et al.*, 2014), and Sweden (this study) suggest that important insights could be derived from collaborative learning across countries.

The national policy changes described in this article indicate that there has been a distinct movement towards implementing the ecosystem approach in Sweden over the study period. We particularly observe changes in funding and policy instruments (first and second order outcomes). However, the changes have come about gradually and in an uncoordinated manner, in part due to political changes and we argue that the observed changes cannot be described as a third-level outcome or paradigm shift. The re-organization of SwAM illustrates the tension between gradual adaptions within the current policy paradigm (evolutionary, second level outcomes) vs. a paradigm shift (revolutionary, third level outcome). The agency was originally organized to break down the traditional barriers between fisheries management and management of the marine environment (i.e. with an intention to achieve an organizational structure that could better integrate different areas from a marine perspective), but by merely focusing on the marine environment, not comprehensively addressing the complexity of freshwater and land-based pollution sources affecting the ecosystem, combined with institutional inefficiency, the agency was re-organized towards a more sectorial structure.

A remaining question is whether a paradigm shift is needed to achieve holistic management of the marine environment (as has been argued by Berkes, 2012), or if the gradual changes observed in the article can eventually deliver the same end results? The answer to this question is yet unclear. We suggest that Sweden need to invest substantially in collaborative learning between central agencies and that scientific networks and NGOs think creatively about new ways to collaborate and coordinate their activities. Sweden should also engage in national and international innovation investments coupled to the marine environment, with a vision to move beyond evolutionary tinkering, see (Jacob, 1977). Such investments should be guided by clearly defined visions and objectives from political leaders and central agencies, while also harnessing the creative power and abilities of local and regional actors. Such engagement would provide international leadership, enable a national paradigm shift and stimulate innovative research. Importantly, such efforts would also substantially improve resource management and the chances of Sweden reaching its environmental quality objectives.

Conclusions

Efforts by Swedish scientists, policy-makers and practitioners have improved the prospects for making the ecosystem approach operational. New national legislation for marine spatial planning is in place and a new agency (SWaM) is developing capacity for cross-sectorial collaboration. Increasingly experienced practitioners and a high degree of public concern are creating conditions for making the ecosystem approach operational, but political leadership, learning and improved coordination is also required. We argue that the time period studied represents a phase of "preparing the system for change" (Folke *et al.*, 2005), but further dynamics require leadership, coordination, bold experiments and possibly, a crisis of sort.

Supplementary data

Supplementary material is available at the *ICESJMS* online version of the article.

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