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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

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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.

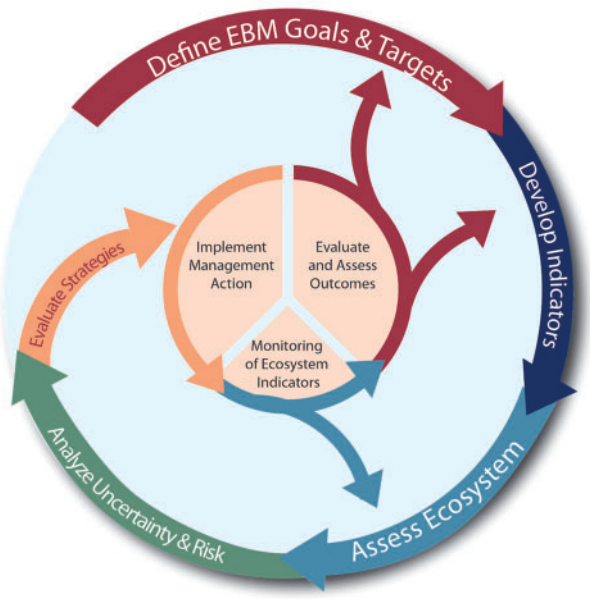

Figure 1. The Integrated Ecosystem Assessment (IEA) loop, outlining the general steps that an IEA iteratively follows to meet the ecosystem-based management (EBM) goals defined at the start of each iteration. From Samhouri *et al.* (2014).

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 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.

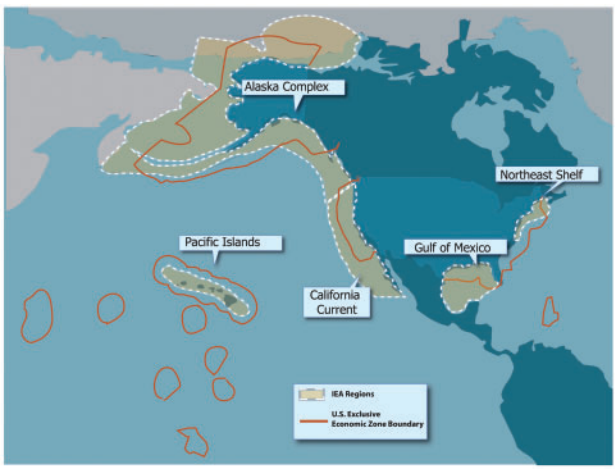

Figure 2. Map of the five active regions in the NOAA IEA program. (Credit: Avi Litwack).

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 ~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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