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Contribution to the Themed Section: 'Integrated assessments'

Original Articles

Why the complex nature of integrated ecosystem assessments requires a flexible and adaptive approach

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This article considers the approach taken by the ICES to integrated ecosystem assessments (IEAs) in the context of the wider evolution of IEAs and the science/policy landscape within the ICES region. It looks forward and considers the challenges facing the development of IEAs, specifically those of scoping for objectives, participatory engagement, developing indicators and targets, risk analysis, and creating tools to evaluate management measures for marine anthropogenic activities. It concludes that expectations that the implementation of IEAs will take an ordered, stepwise approach will lead to disappointment and frustration. This is a consequence of the need to operate in an adaptive manner in a complex system. The ecosystem, the science support infrastructure, and the governance systems are all complex. Plus when engaged in a debate about societal objectives, we expect to encounter a complex and changing landscape. As a community, the challenge is to find leverage mechanisms to encourage IEA efforts to provide insights and tools within resources. We will need to innovate and be responsive to the complexity of the ecosystem and governance structures encountered when performing IEA.

Keywords: ecosystem approach, fisheries, HELCOM, MSFD, OSPAR, regionalization.

Introduction

The concept of integrated ecosystem assessments (IEAs), in the marine sphere, germinated in response to the development of the ecosystem approach to fisheries management (EAFM, Rice 2011). The political incentive behind EAFM is clear (Murawski, 2007; Jennings and Rice, 2011), but operationalizing it has been, and still is, a challenge (Rice, 2011). The ecosystem approach is certainly not a new approach (Jennings, 2004; Garcia and Cochrane, 2005) but it requires management to take a different path, although perhaps not a paradigm shift, to be successful (Sissenwine and Murawski, 2004; Murawski, 2007). Core to the ecosystem approach is managing the impact, or the pressure of humans on the marine ecosystem; the human dimension (De Young *et al.*, 2008; Rice, 2011). Jennings (2004) sums this up as "The ecosystem approach is variously defined, but principally puts emphasis on a management regime that maintains the health of the ecosystem alongside appropriate human use of the marine environment, for the benefit of current and future generations."

Jennings and Rice (2011) suggest that progress towards an ecosystem approach to fisheries has been slow because of the lack of specific environmental, social, and economic objectives, with no agreed guidance on trade-offs from policy-makers. They add that it is impacted by a framework for decision-making in Europe with a fisheries policy that is skewed towards short-term national interests. It is likely that the lack of guidance for trade-offs and objectives and a reluctance by those engaged in the debate to bring non-ecologists to the table will hamper any push towards developing tools for the ecosystem approach (Degnbol and McCay, 2006; Francis *et al.*, 2011). "The challenge for EAM/EBM will be to link the incremental changes in selected indicators to a target end state to the societal costs and benefits of achieving the end state " (Murawski, 2007).

Part of making an ecosystem approach operational is ensuring that the interactions between fisheries and other sectors are equitable, with inclusiveness in decision-making (Levin *et al.*, 2009; Rice, 2011). This has led to the development of IEAs as a concept (Link, 2012), although like the ecosystem approach, it is difficult

to provide a working definition for IEAs as they encompass a framework and executable practice. The ICES "benchmark" group on IEA (WKBEMIA) defined IEA as an interdisciplinary process of combining, interpreting, and communicating knowledge from diverse scientific disciplines, in such a way that the interactions of a problem can be evaluated and thus provide useful information to decision-makers (ICES, 2012a). Levin *et al.* (2009) define IEA as "a synthesis and quantitative analysis of information on relevant physical, chemical, ecological and human processes in relation to specified ecosystem management objectives". Defining IEA is a challenge, especially because the suggested approach to IEA is adaptive and iterative; learning by doing (De Young *et al.*, 2008). I see IEA as a process that leads to the provision of joined-up and consistent advice that addresses society's needs to manage anthropogenic pressures on the marine ecosystem. Importantly, it does not lead to one answer, but provides the information and knowledge to facilitate exploring the space for decision-making and policy development. It is regional in scope. In the ICES context, there is a distinct difference between IEA and developing models of ecosystem functioning. A framework to make the IEA approach operational has been evolving and can be traced through the documents from FAO (2003), ICES (2005), and Levin *et al.* (2009). The framework can be summed up as scoping, developing indicators and targets, risk analysis, assessing ecosystem status, then evaluating the strategy and return to any previous stage that requires further development (Levin *et al.*, 2009). Samhouri *et al.* (2014) explore this framework further with specific case studies from the USA.

In an inherently chaotic system, we should aim to manage anthropogenic impacts in an integrated manner and respond to unforeseen changes as they occur without the requirement to be able to quantify every functional relationship (Schellnhuber and Sahagian, 2002; Clark *et al.*, 2005). This requires an iterative process linked to adaptive management. Linking a scientific investigation to a societal debate on management objectives, trade-offs, and tools for analysis may well challenge those that see science as a search for pure truth and not part of a societal debate. Many argue that the science is not yet good enough, nor based on strong enough evidence to enter that debate. To paraphrase myth number 4 in Murawski (2007), people think that insufficient information limits the application of the ecosystem approach. This is also allied to the idea that a quantitative model of species interactions among all components is necessary to guide the ecosystem approach (myth 8 in Murawski 2007). It is necessary to understand the broad dynamics of the ecosystem state and function (a "macroscope" approach, Schellnhuber and Sahagian, 2002). However, we will never understand all the processes, and even if we did, it is unlikely that full understanding would make our political decision-making easier. Rice (2011) stresses that the process must maximize the use of available information rather than emphasize the areas of uncertainty. Likewise, the idea that we can "data-collect" our way to the ecosystem approach, or an IEA, must be recognized as a fallacy. Levin *et al.* (2009) point out that massing data simply cannot tell us how to implement EBM or determine priorities for management. They say that reductionist approaches can result in researchers and policymakers "drowning in data but gasping for knowledge". Tallying the status or trends of various components cannot inform EBM (Levin *et al.*, 2009). As Degnbol *et al.* (2006) claim, "improvements in fisheries management will be realized not through the promotion of technical fixes but instead by embracing and responding to the complexity of the management problem".

In this article, I reflect on my experience of working with IEA groups over the last 2 years. I consider the approach taken by the ICES community through it IEA groups in the context of the wider IEA debate. I also look forward and consider the challenges that face the development of IEAs, specifically those of scoping for objectives, developing indicators and targets, risk analysis, and creating tools to evaluate measures to manage marine anthropogenic activities. Almost all researchers involved in the development of IEAs recognize that an adaptive and iterative process is crucial to success (Samhouri *et al.*, 2014). However, many members of the ICES community have expressed frustration over the "institutional and governance structures" and the limited resourcing of development that challenge implementation of IEAs (ICES, 2012a; Walther and Möllmann, 2014). In this article, I would like to explore whether a clearly prescribed framework or high-level strategic steering can be expected (Levin *et al.*, 2014; Möllmann *et al.*, 2014), and whether its absence is a block on progress?

ICES approach

The organizational approach used to develop IEAs by ICES is described in Walther and Möllmann (2014). This approach has evolved mostly through the efforts of individual researchers to build multidisciplinary teams and is characterized by regional groups, each acting in slightly different ways, to address slightly different challenges. There is one group based in the northwest Atlantic, but the majority of groups work on European regional seas. The new ICES strategic plan (ICES, 2014) places developing integrated ecosystem understanding at its core for the next 5 years. This puts the regional groups at the centre of the ICES network. From the start, it is important to note that none of the

Table 1. ICES IEA Working Groups that were considered in this article, including plans for their future.

Region	Group	Years active	Future plans*
Baltic Sea	WKIAB	2006	
	WGIAB	Annually 2007 to present	2014, 2015
Northwest Atlantic	WGNARS	Annually 2010 to present	2014, 2015, 2016
Northeast Atlantic	WGEAWESS	2011 and 2013	2014, 2015, 2016
North Sea	WGHAME	2010	
	WGINOSE	Annually 2011 to present	2014, 2015, 2016
Norwegian Sea	WGINOR	2013	2014, 2015
Barents Sea	WGIBAR	Yet to meet	2014, 2015, 2016

*Agreed terms of reference for these years.
WKIAB- ICES/BSRP/HELCOM, Workshop on Developing a Framework for Integrated Assessment for the Baltic Sea; WGIAB-ICES/HELCOM, Working Group on Integrated Assessments of the Baltic Sea; WGNARS, Working Group on the Northwest Atlantic Regional Sea; WGEAWESS, Working Group on Ecosystem Assessment of Western European Shelf Seas; WGHAME, Working Group on Holistic Assessments of Regional Marine Ecosystems; WGINOSE, Working Group on Integrated Assessments of the North Sea; WGINOR, Working Group on the Integrated Assessments of the Norwegian Sea; WGIBAR, Working Group on the Integrated Assessments of the Barents Sea. More complete descriptions of the groups are given in Walther and Möllmann (2014).

groups have been asked, or proposed themselves, to carry out an actual ecosystem assessment as yet. The groups have been tasked with developing methods and tools for IEAs. When reading the reports of the ICES IEA groups (Table 1, and see Walther and Möllmann, 2014), certain frustrations become apparent. The groups ask for high-level stewardship, there is a crying out for a simpler governance structure and clearer defined management objectives. A huge amount of work has been done by the groups and the outputs have been substantial, with analysis of trends in the state of the ecosystems, much focus on fisheries issues and initial exploration of the Levin *et al.* (2009) approach. When reading the reports, it is also evident that some groups have fallen into traps that could hamper development of IEAs.

In my mind, there are some key issues that researchers need to consider when pushing forward IEA. These key issues are based on the work by FAO (2003), ICES (2005), and Levin *et al.* (2009) and can be grouped into the concepts and techniques (the practical method development and implementation). The key concepts are:

(i) The human dimension—acknowledge that humans are central to the challenge. IEAs are management tools for maintaining the health of the ecosystem alongside the appropriate human use of the marine environment. IEAs are as much about a societal debate as about the results of a scientific study.

(ii) Ecosystems vary—there is no such thing as a marine ecosystem in equilibrium. This means that predictions beyond are known knowledge should be challenged and the state of the ecosystem should always be monitored. Links between components of the system and potential responses to management action will not be linear. Approaches that suggest that the future will behave like the past should be challenged.

(iii) Seek operational objectives—they are the cornerstone of IEAs. They are not usually predetermined, but best derived through a debate where stakeholders explore the consequences of their objectives through models and other tools. The process of how the objectives are derived might be complex and multilayered.

(iv) Integrate across sectors—IEAs should aim to integrate across issues, sectors, and stakeholders. Although individual projects or teams should always define the scope and limits of their work.

(v) Understanding is what matters—data acquisition is different from knowledge acquisition. You will never fully understand the system in which you operate, and it will always change. Collecting data in isolation without synthesis and testing of ideas will not build knowledge but be aware that even a full understanding will not replace the societal debate required to make decisions.

(vi) Do it again and again—it is an iterative process. The methods being developed should be part of an adaptive management framework that will constantly evolve and change based on knowledge acquisition and the priorities of society.

On the practical side, the techniques used should consider:

(i) Scoping—of societal, managerial, and operational objectives. In addition to this, it is important to set spatial boundaries and the subdivision of regions in relation to ecosystem dynamics and management objectives. It is also practical to set the sectoral boundaries too.

(ii) Monitoring—collecting datasets and monitoring of the ecosystem. This should be associated with ecosystem modelling with the overall aim to review the state of the system and monitor progress of indicators in relation to thresholds or targets.

(iii) Developing indicators, targets, and reference points—developing indicators for ecosystem functioning, performance of management measures, decision rules, or communication of management objectives and action. These indicators must be associated with targets and reference points.

(iv) Assessing cumulative effects—develop methods (quantitative or qualitative) for assessing a range of anthropogenic pressures both unisectoral and multisectoral. Methods for combining indicators need to be developed to allow an IEA to reach an overall conclusion about the state of the ecosystem.

(v) Risk analysis—exploring risk analysis tools to provide information on potential scenarios and trade-offs associated with specific decisions. Examining trade-offs by looking at risk analysis in relation to potential management objectives from across sectors, or choices within a single sector.

What follows below is my personal interpretation of how we have explored the key ideas of IEAs in ICES. It is based on my reading of reports and discussions with the active IEA groups. The aim of my comments is to explore what we mean in practice in ICES when we work on IEAs and are aimed at setting the stage for the further development of IEAs throughout the ICES community.

ICES in its new strategic plan has set the target of carrying out example IEAs in the next few years, so the efforts of the ICES community now needs to include the execution of IEAs along with the further development of methods and tools. The current IEA groups were tasked with method development. All groups have made progress on building datasets and considering monitoring needs. They acknowledge the need to set boundaries (regional, discipline, and sector). Many suggest dividing their regions based on ecosystem functioning, and a few appear to have considered the impact of these divisions on management. Almost none of the groups have carried out an effective scoping exercise. This is despite links with regional seas conventions and probably reflects their interpretation of method development being their central purpose. Most groups suggest that governance issues prevent either participatory approaches or integration of management across marine sectors, which suggests that carrying out a scoping exercise is crucial to method development and IEA implementation.

With regard to the overall concept of IEAs, there still appears to be a reluctance to think conceptually about the human dimension. It is not clear whether all the groups see IEA as tools to balance diverse societal objectives. Some appear challenged with the concept that indicators can exist that address societies priorities rather than ecosystem functioning. All groups acknowledge that ecosystems are influenced by a range of drivers that impact at differing time-scales. Studies examining the trends in the state of the ecosystem dominate some of the groups. Every group reports that they are struggling to work across sectors. Some groups appear unclear about the concept of adaptive management, whereas others are developing techniques to make use of their improving understanding. Many groups prioritize data collection. As yet, there appears to be limited progress on developing methods to synthesize knowledge to inform or explore potential management action. In my mind, some IEA researchers see themselves as teams working on ecosystem

description rather than IEAs as defined by WKBEMIA (ICES, 2012a) or Levin *et al.* (2009).

The groups seem most confident and happiest when working in the core ICES disciplines of fisheries and the ecology of marine vertebrates and copepods. Biodiversity and habitat quality/connectivity have been considered by a minority of groups. On the European side, up until 2013, no groups had really considered non-fishing-related pressures, but that has recently changed, especially with the development of the ecosystem overviews (ICES, 2013a; Walther and Möllmann, 2014). Some participants appear to be aware of the multiple roles played by indicators, and the contrasting ideas of indicators and targets for management and monitoring of the ecosystem state. The groups appear challenged by the prospect of proposing indicators; this is despite the large amount of work on indicators that has been published by the ICES group WGECO (ICES, 2013b) over the last decade. Most groups have had terms of references that asked for indicator development and delivery, but few indicators have been forthcoming. Few IEA groups, as yet, have suggested thresholds, targets, or reference points for integrated advice, although the Baltic IEA group has provided advice on future scenarios for multispecies options for Baltic fisheries (Möllmann *et al.*, 2014). Proposing targets or reference points would facilitate a dialogue to start with policy developers. In recent years, some groups have begun developing risk-based approaches and exploring methods to explore trade-offs.

The conclusion of the ICES Benchmarking workshop on IEA (ICES, 2012a) was that almost none of these key concepts or activities can be carried out in isolation or in a specific order. They developed the idea of an IEA cloud, where the iterative process is not circular, or linear, but is structured as a multidimensional matrix. It is well known that a multidimensional approach is difficult to steer, and no one individual can be fully aware of all activities and all links, so the approach stresses the importance of teams working towards a shared vision, with a strong need for communication between the main players.

Looking forward

Considering all these issues, we must explore the opportunities offered by the current system and view the perceived limitations as challenges. Governance mechanisms are always challenging; whether in Europe or North America. Resources are becoming ever more limited, despite large increases in governance challenges. Society expects informed decisions from policy developers and yet seems unprepared for the resource implications of that expectation. The sections below with further explore how we can use the strengths in the ICES community to further develop IEAs specifically on the key techniques of scoping, use of indicators, risk analysis, and tools for management strategy evaluations.

Scoping

A concern of the ICES IEA groups, and a key factor in an IEA, is a scoping exercise to establish higher and lower (operational) objectives for managing the impact of humans on the ecosystem (Levin *et al.*, 2009). You should "balance diverse societal objectives" (FAO, 2003). This is no mean feat as the perceived reality of each stakeholder will be based on a different understanding of the functioning of the system (Verweij and van Densen, 2010) and, thus, probably lead to a different notion of the impact of a management action on their activity (Delaney and Hastie, 2007). Policy objectives and research initiatives are in a state of continuous flux; observe the shift in terms of research priorities from environmental protection to "green growth" in the EU Horizon 2020 research programme. It is often said that scoping is an initial activity, but in reality scoping is required continuously throughout the process (ICES, 2012a; Samhouri *et al.*, 2014). In ICES, a wealth of experience has been generated in describing objectives through participatory modelling of single stock fisheries management plans (where scientists and stakeholders work together to build and explore the models used to test management plans) and exploring policy objectives for marine spatial planning (e.g. Schwach *et al.*, 2007; Degnbol and Wilson, 2008; Mackinson *et al.*, 2011; Dankel *et al.*, 2012; Röckmann *et al.*, 2012). This participatory approach is really what is required in IEA. Scoping must be a dialogue between stakeholders. Often the policy developers, industrial concerns or NGOs are not aware of the potential options and trade-offs until they see the ability of the tools or the dynamics of the models. Scientists can operate as "transparency brokers" exploring policy options with the range of stakeholders (P. Degnbol, ICES, pers. com.), thus providing useable knowledge (Haas, 2004). Our experience in ICES of developing multispecies advice for the Baltic and North Sea shows that a key aspect of providing advice is finding the appropriate communication approach to describe the trade-offs (ICES, 2012b). This communication approach comes before any consideration of the management/policy objectives. Assuming that policy developers know what they want before an IEA exercise is unrealistic. Assuming that there is one set of unified managers, with one objective, is even more unlikely (van Leeuwen *et al.*, 2012).

One of the most important parts of the scoping exercise is to establish boundaries around the conceptual space being covered by the IEA, the factors that will be integrated and the objectives that will be included. The range of relevant time-scales, from short-term goals to longer-term objectives, must also be scoped so that developers of IEAs are aware of the multiple spatial and temporal scales at which IEAs operate (De Young *et al.*, 2008).

In some cases, the policy agenda jumps ahead of science know-how (Rice, 2011). A good example of this is the Marine Strategy Framework Directive (MSFD; EC, 2008) in the EU. The MSFD can be viewed as an imposition and clarification of the higher management objectives (Good Environmental Status, GES) for the EU marine environment including fisheries (Ratza *et al.*, 2010). However, in practice, many suggest that the MSFD is ambiguous with unclear boundaries and conflicting objectives (van Leeuwen *et al.*, 2012; Ounanian *et al.*, 2012). Trying to define the operational objectives and the indicators from the MSFD is difficult with the GES descriptors being a mixture of ecosystem components, attributes, and pressures (S. Jennings, CEFAS, pers. com.). However, it can be viewed as the result of a politically imposed scoping exercise. Thus, in the EU, despite the MSFD's ambiguities, researchers have a set of objectives by which to operate. The remaining challenge is to resolve the issue of trade-offs and priorities for the multitude of GES descriptors. Few natural scientists have experience operating in a participatory process as "transparency brokers" and developing indicators that relate to societal interests/priorities. Researchers may feel awkward moving from their training in biology/ecology into the participatory decision-making realm, but this is what is required.

Indicators and targets

Indicators can be viewed as an interface between science and policy (Heink and Kowarik, 2010) with some arguing that they have more value to policy-makers than to scientists (Levin *et al.*, 2010). Indicators are needed to provide information on the state of the

ecosystem, and the progress of management in relation to objectives (Jennings, 2005). Indicators are quantifiable metrics that reflect changes in ecosystem attributes (Samhouri *et al.*, 2009) and the performance of an indicator is quantified by the ability to detect and/or predict trends in ecosystem attributes (Fulton *et al.*, 2005). We also require metrics for monitoring overall state, and I would class these monitoring indicators as conceptually different from IEA indicators, which are target-oriented and specific for management action.

There is a wealth of studies on defining indicators and targets for both the marine ecosystem-based approach and IEAs. Most are based on case studies and often use different ecosystem or trophic models to test the how the indicators are chosen and the suitability of the indicators themselves (Trenkel and Rochet, 2003; Fulton *et al.*, 2005; Methratta and Link, 2006; Samhouri *et al.*, 2009; Kershner *et al.*, 2011). It is paramount to remember the purpose of indicators. As Levin *et al.* (2010) says: "It is tempting for natural scientists to advocate indicators that provide maximal information about ecosystem structure and function without consideration of societal values". Providing maximal information on ecosystem structure and function may negate the indicators' role in melding social and natural science (Levin *et al.*, 2010). Informing society that an ecosystem is changing in a dramatic manner without indicating what it means or how to resolve the problem would negate an indicators role. In the ICES context, the policy objectives cannot be forgotten. The optimal portfolio of indicators is one that ensures appropriate scientific information is captured while also maximizing the value of the indicators for policy-makers (Levin *et al.*, 2010). As indicators sit at the interface between science and policy they should be expected to change over time as society's objectives change (Samhouri *et al.*, 2012). There are often very pressing needs which can be quickly addressed (Jennings and Le Quense, 2012) and marine scientists that work in the applied field should be careful not to deflect focus away from the main issues.

Indicators (with associated targets/reference points) serve several purposes; to define the expected objectives, track progress towards those objectives and communicate trends in complex impacts to a non-specialist audience (Fulton *et al.*, 2005; Jennings, 2005). The portfolio of indicators should contain complementary indicators that exclude redundant metrics, i.e. be resource efficient (Samhouri *et al.*, 2009; ICES, 2013b; Large *et al.*, 2013). Rice and Rochet (2005) stress that the number of indicators should be limited, as indicators will be incorporated into a range of roles and must be communicable to a wider audience. Some potential indicators will reflect the same trends in ecosystem attributes over time; Levin *et al.* (2010) comment that this might be the case for some societally important indicators (e.g. abundance of different species of large sea mammals) which also do not provide that much information on ecosystem functioning. The building of the portfolio will involve compromise.

Much has been said about the selection process for indicators. Levin *et al.* (2010) describe this process as indicator mapping. Nonetheless, there is broad agreement about the criteria for assessing indicators (ICES, 2013b). The indicators must be sensitive and specific to changes in ecosystem attributes and responsive to changes in human activities (Rice, 2003; Jennings, 2005; Rice and Rochet, 2005). Rice and Rochet (2005) provide an 8-step framework for selecting indicators, including scoping. They list the important criteria as concreteness, theoretical basis, public awareness, cost, measurement, availability of historical data, sensitivity, responsiveness, and specificity. The criteria appear to be accepted by the research community and have been further developed by ICES (2013b). The 8-stage framework can lead to subjective choices (Rochet and Rice, 2005; Piet *et al.*, 2008). Fulton *et al.* (2005), Samhouri *et al.* (2010, 2012), and Kaplan *et al.* (2012) use ecosystem models to assist in the selection of appropriate indices. There is a danger that when working with indicators you assume that causalities are linear (Samhouri *et al.*, 2010, 2012). This approach appears to ignore the likelihood of alternative stable states, hysteresis, and inherent non-linearity in the underlying responses of the ecosystem (Heath, 2012; Denderen and Kooten, in press).

As part of their method development, it would be constructive for the IEA groups in ICES to further consider indicators and engage with policy developers to show the ramifications of decisions about targets. Many nations have independently proposed indicators through the MSFD, and both OSPAR and HELCOM (the regional sea conventions for the NE Atlantic and the Baltic, respectively) now have long lists of either proposed or potential indicators. So some management objectives and associated indicators have been provided. The ICES IEA groups are in a strong position to explore whether these indicators are of value and show their relative utility.

Risk

Risk analysis provides an accountable and transparent framework for prioritizing actions in management, particularly in the broader context of the ecosystem approach to fisheries (ICES, 2009). Samhouri and Levin (2012) propose that ecosystem-based risk should be scored along two axes of information: the exposure of a population to an activity and the sensitivity of the population to that activity. Following the same line of argument about scoping and indicators, the subjective value-based nature of objectives requires recognition that risk analysis is a decision support tool, not a decision-making tool. Risk analysis can also bring in factors such as cost of monitoring or research into the decision-making process. It is often argued that first a qualitative assessment of risks be undertaken (a screening out of low-risk activities) followed by a detailed assessment (often quantitative). Some IEA groups suggest that risk analysis should be operationalized into a predictive measure of the effectiveness of management actions, rather than an exploration of trade-offs.

Accounting for the unpredictability of human behaviour is also a challenge when investigating fisheries systems (Fulton *et al.*, 2011). The following uncertainties may need to be assessed when considering any fisheries management cycle; resource dynamics, reporting, monitoring, assessment, management decisions, implementation, and fishing activity (Fulton *et al.*, 2011). This approach appears to be just as valid when considering any anthropogenic pressure on the system. When thinking about IEAs specifically, the error and scale of the chosen indicators should be considered, thus accounting for the degree of signal and noise (Jennings, 2005). If managers respond and act based on noise rather than signal, they risk squandering the credibility of everyone involved (Jennings, 2005). Thus, an assessment of risk is crucial.

Developing tools and evaluations of strategy

ICES has many in-house experts in management strategy evaluation, but they tend towards evaluating the effect of single-species fisheries on single-species populations (Kraak *et al.*, 2010). There are notable exceptions where scientists have started to consider the other effects of fishing activities on multispecies targets, the effect of mixed fisheries, closed areas, and impact on benthic

communities and on elasmobranchs (Mackinson *et al.*, 2009; Ulrich *et al.*, 2011; Gascuel *et al.*, 2012; Kraak *et al.*, 2012; Rijnsdorp *et al.*, 2012, etc.) but studies that integrate across pressures or that investigate cumulative effects are still rare (Stelzenmüller *et al.*, 2010; Foden *et al.*, 2011). There are various examples of good practice of management evaluation coming from IEA work (*Sainsbury et al., 2000*; Smith *et al.*, 2007; Ojaveer and Eero, 2011; Heath, 2012; Kaplan *et al.*, 2012, 2013).

Jennings and Rice (2011) suggest a two-tier approach to evaluating impact and potential management measures, by assessing both single-sector and multisectoral activities. There appears to be progress in understanding single-sector impacts, with researchers considering the effects of one type of activity on many components of the ecosystem. Cumulative effects should consider how social and economic aspects of ocean uses covary or compete and how impacts of multiple ocean uses contribute to status and trends of

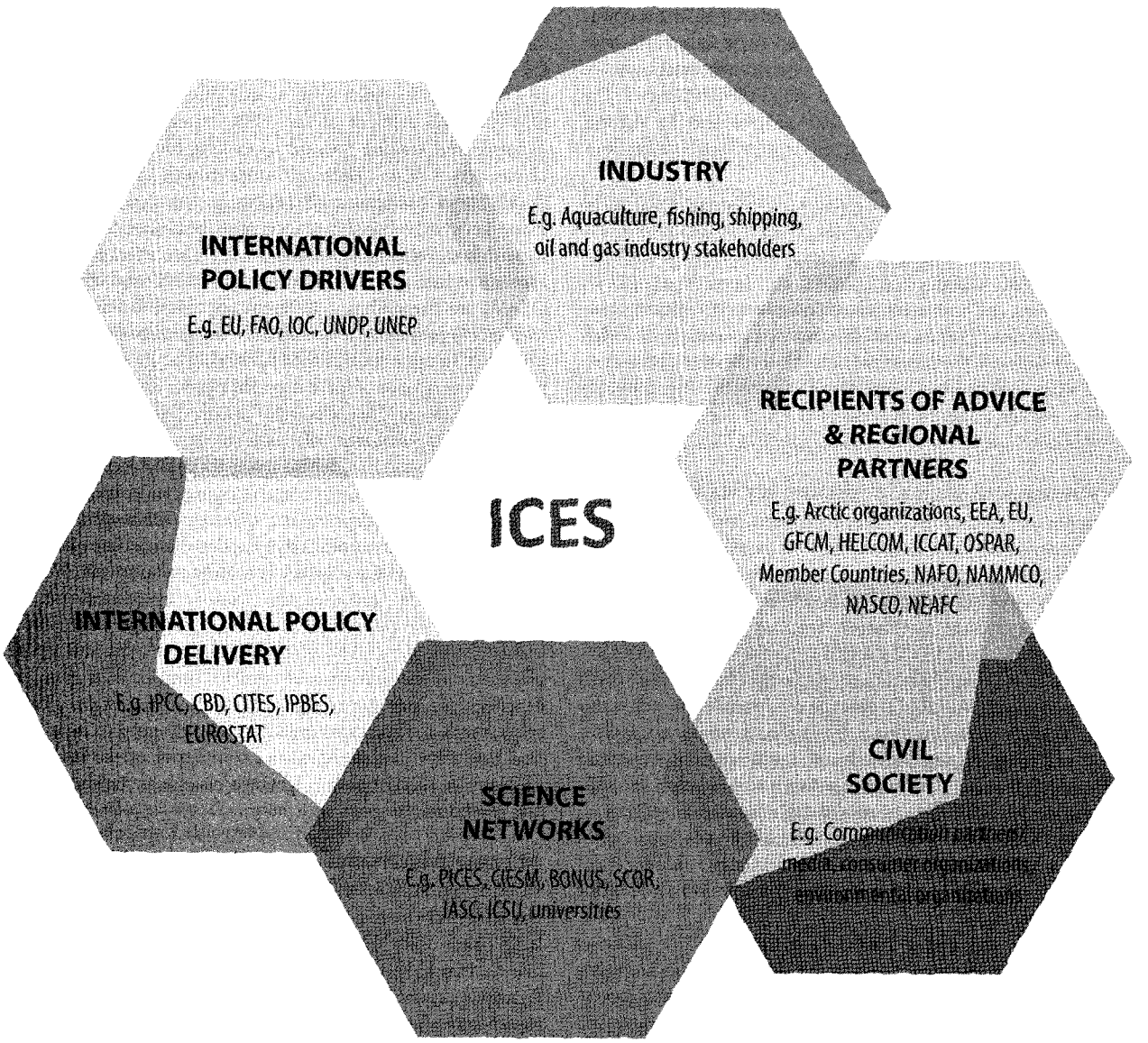

Figure 1. The description of the science and policy landscape in which ICES operates, taken from the ICES strategic plan (2014–2018; ICES, 2014). © ICES. The examples are not exhaustive. Acronyms: Baltic Marine Environment Protection Commission (HELCOM), Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR), Convention on Biological Diversity (CBD), Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), European Environment Agency (EEA), European Union (EU), Food and Agriculture Organization of the United Nations (FAO), General Fisheries Commission in the Mediterranean (GFCM), International Arctic Science Committee (IASC), International Commission for the Conservation of Atlantic Tunas (ICCAT), International Council for the Exploration of the Sea (ICES), International Council for Science (ICSU), Intergovernmental Panel on Climate Change (IPCC), Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES), Intergovernmental Oceanographic Commission (IOC), Mediterranean Science Commission (CIESM), Northwest Atlantic Fisheries Organization (NAFO), North Atlantic Salmon Conservation Organization (NASCO), North Atlantic Marine Mammal Commission (NAMMCO), North East Atlantic Fisheries Commission (NEAFC), North Pacific Marine Science Organization (PICES), Scientific Committee on Oceanic Research (SCOR), Statistical Office of the European Communities (EUROSTAT), United Nations Development Program (UNDP), United Nations Environment Program (UNEP).

ecosystem components or attributes. Cumulative effects will not be additive but be complex and responsive (ICES, 2012c). A multisectorial approach may lead to the conclusion that one sector dominates the anthropogenic impact (e.g. the impact of fishing on benthic communities; Foden *et al.*, 2011), which is a useful finding when looking at the next stages of implementing management actions, but you need a multisectoral approach to arrive at this conclusion. It has also been suggested that cumulative assessments across multiple sectors are extremely sensitive to the assumed weightings between sectors (Stelzenmüller *et al.*, 2010). This area of research needs much more attention and Rice suggests that the initial barrier to development is a lack of cross-sectoral datasets, and institutional blocks to exchange between researchers from individual sectoral fields (J. Rice, pers. com., DFO, Canada). The move to integrated data management policies and in Europe, closer collaborations with (and between) regional sea commissions will hopefully aid this process.

The ICES IEA groups were instigated to develop methods for the advisory process. Their role was to provide tools and methods. Thus, the groups were not expected to carry out complete IEAs as described by FAO (2003), ICES (2005), and Levin *et al.* (2009), namely to assess the ecosystem status and evaluate potential management strategies. They should, however, be encouraged to pick up any developmental requirements after the evaluation of the strategy and work on following iterations of the process. It is probably now time for the advisory process of ICES to use the tools that have been developed by carrying out example IEAs.

The science and policy landscape for IEAs in ICES

Governance and research structures are layered, complex, and often contradictory with poor communication between those layers. There is no central funding mechanism, no simple decision-making body, and society does not speak with one voice. Within ICES, we need to find a leverage mechanism that can encourage the IEA groups to continue progress. Society also has the right to make decisions based on its evolving political processes. We must note myth number 5 of Murawski (2007); that the ecosystem approach is too difficult to apply in multinational regional management organizations. Complexity in governance should not be an excuse to avoid developing approaches. The balance between conservation and utilization strategies will be a matter of societal choice and negotiation, consistent with the operating principles of any agreement (Murawski, 2007). Therefore, to succeed, we must embrace the complexity of the decision-making and implementation framework (Degnbol *et al.*, 2006).

The science and policy landscape in which ICES scientists operate is complex (Figure 1, taken from ICES 2014). ICES scientists are experienced in describing and exploring complex marine ecosystems. When considering IEAs, they must prepare to enter the complex system of governance and participatory engagement in the translation of societal objectives into their assessments, or at least work in teams that include researchers that are prepared to engage in dialogue with the governance system. We can learn from "complex systems science" that our frameworks are useful to conceptualise our challenges, but new structures and approaches emerge from engagement in a complex system (Mitleton-Kelly, 2003). Adaptability of the approach taken is key. It could be argued that ICES scientists had little direct input into the two main outcomes of the 2014 EU Common Fisheries Policy (CFP) reform, namely the landing obligation (discard ban) and the firming up of the political meaning of the MSY. EU society has accepted a triumvirate EU governance mechanism (Commission, Council, and Parliament) that led to this reform and the mechanism is complex and the outcome unpredictable. Now that the CFP reform has been agreed upon, ICES scientists have to assess its consequences for the sustainability of fisheries. We will be adaptive and iterative in our approach to the reformed CFP. Should we expect any less of our approach to IEAs?

Conclusion

There have been significant advances in the development of integrated ecosystem approaches in ICES, especially on investigating variability in environmental drivers and the incorporation of fisheries management trade-offs in a dynamic ecosystem (e.g. multispecies catch options in Baltic Sea fisheries). IEAs are now a central element of the ICES strategy. The community is dynamic and looking forward to making further progress on the challenges of IEAs. There are opportunities and, as shown by Walther and Möllmann (2014), incremental progress has been made. Ecosystem-based management (EBM) is a US national priority within the National Oceans Policy, and to affect EBM, the IEAs are seen as best practice. In Europe, the MSFD and HELCOM and OSPAR are demanding a different approach to science and new methods to providing advice on the management of anthropogenic pressures. In my view, IEA research should be encouraged that considers the portfolios of indicators, should develop tools for evaluating management measures (that incorporate risk), and should further develop dialogue with stakeholders.

When engaging in a debate about societal objectives, we should expect to encounter a complex and changing landscape. Thus, our response should be adaptive and iterative. The expectation of an ordered process is not only likely to lead to disappointment and frustration, but is also actually not an optimum approach. We should plan, and build strategies that can be measured, but those plans should be responsive as we expect change and unforeseen consequences of our actions. The field of managing anthropogenic pressures on the marine ecosystem is complex with many interdependencies, but the challenge is to provide insights from our science with the resources available. We will need to innovate and find new ways to respond to the complexity of the management problem. A straight path might not necessarily be the route that gets you home.

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