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Introduction to the Symposium: '*Marine Socio-ecological Systems Symposium*'

Introduction
Keeping Humans in the Ecosystem

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The World Ocean presents many opportunities, with the blue economy projected to at least double in the next two decades. However, capitalizing on these opportunities presents significant challenges and a multi-sectoral, integrated approach to managing marine socio-ecological systems will be required to achieve the full benefits projected for the blue economy. Integrated ecosystem assessments have been identified as the best means of delivering the information upon which marine resource management decisions can be made. By their nature, these assessments are inter-disciplinary, but to date have mostly focused on the natural sciences. Inclusion of human dimensions into integrated ecosystem assessments has been lagging, but is fundamental. Here we report on a Symposium, and the articles emmanating from it that are included in this Theme Set, that address how to more effectively include human dimensions into integrated ecosystem assessments. We provide an introduction to each of the main symposium topics (governance, scenarios, indicators, participatory processes, and case studies), highlight the works that emerged from the symposium, and identify key areas in which more work is required. There is still a long way to go before we see end-to-end integrated ecosystem assessments inclusive of all the major current and potential ocean use sectors that also encompass multiple aspects of human dimensions. Nonetheless, it is also clear that progress is being made and we are developing tools and approaches, including the human dimension, that can inform management and position us to take advantage of the multi-sectoral opportunities of sustainable blue growth.

Keywords: ecosystem-based management, governance, indicators, integrated ecosystem assessment, marine socio-ecological systems, modelling, scenario analysis, stakeholder engagement.

Introduction

The World Ocean is an essential component of global economic activity and development. A majority of countries are exploring the potential of blue growth, supported by both well-established economic sectors (maritime transport, fisheries and aquaculture, coastal tourism, oil and gas exploitation, recreation, dredging, etc.) and new industries still developing their full potential (renewable marine energy, deep-sea energy and mineral extraction, new forms of aquaculture like seaweed farming, marine biotechnologies, etc.). The OECD (2016) estimates the ocean economy will more than double to over US$3 trillion by 2030, and argues that the critical need is to adopt multi-sector perspectives for management, with coordinated and coherent long-term strategies, clearer regulation and allocation of rights, and greater international cooperation. The challenge in supporting enhanced equitable (http://www.undp.org/content/undp/en/home/sustainable-development-goals/goal-10-reduced-inequalities/targets/) and sustainable uses of marine ecosystems is to enable current and future growth in this blue economy, maintaining and facilitating the development of coastal livelihoods while not compromising the sustainability of social, economic or environmental outcomes (UNEP, 2006; Díaz *et al.*, 2015; Long *et al.*, 2015; Inniss *et al.*, 2016; United Nations, 2016; Burgess *et al.*, 2017). This challenge explicitly involves managing human impacts on the earth's marine and coastal systems, and managing the feedback of these impacts on coastal communities, industries, and stakeholders.

Meeting this challenge can be facilitated by an integrated understanding of marine socio-ecological systems (Charles, 2001; Rice and Garcia, 2001; Kooiman *et al.*, 2005; Ommer *et al.*, 2011; Kittinger *et al.*, 2013; Begg *et al.*, 2015; Link and Browman, 2014, and references therein). Fully integrated ecosystem assessments take into account the relationships among marine ecosystem components, how marine ecosystems are structured and function, how marine ecosystem goods and services are produced, maintained and utilized, how governance of marine socio-ecological systems are structured and implemented, and how this all contributes to the development of the blue economy and associated distribution of benefits to society (IPBES, 2015; Cormier *et al.*, 2017; ICES, 2016; Burgess *et al.*, 2017; Lillebø *et al.*, 2017). Reviewing our progress and current capacity to evaluate the global state of marine socio-ecological systems is needed, is timely, and has not been done systematically. Many methods, approaches and tools for such integrated ecosystem assessments have been developed during the last two decades, as have processes for using these assessments in policy development and management (Link and Browman, 2014; Dickey-Collas, 2014; IPBES, 2015). To take stock of the status of this discipline, and to identify key scientific challenges ahead, an international symposium on "Understanding marine socio-ecological systems: including the human dimension in Integrated Ecosystem Assessments" (MSEAS) was held in Brest, France, from 30 May to 3 June 2016 (http://www.ices.dk/news-and-events/symposia/MSEAS/Documents/programme_mseas_2016.pdf;ttp://www.ices.dk/news-and-events/symposia/MSEAS/Documents/BookOfAbstractsUpdateJune.pdf). The focus of the symposium was on integration and assessment across multiple ocean uses and sectors. There was a particular emphasis on the methodological and empirical challenges involved in including human dimensions in integrated ecosystem assessments, as well as the governance considerations and processes which such assessments can inform. The symposium was global in scope, with a focus on regions in which integrated ocean management policies have been developed and implemented in the last two decades. A key aspect of this symposium is that it provided an opportunity for information exchange among scientists, researchers and practitioners, from a wide range of different disciplinary backgrounds, with those involved in the development of ocean policies and governance.

The past few years have seen a growing literature on the general theme of integrated ecosystem assessments (Dickey-Collas, 2014; Levin *et al.*, 2014; Samhouri *et al.*, 2014; Walther and Möllmann, 2014; Link and Browman, 2017; Dickey-Collas, 2014; DePiper *et al.*, 2017) and its associated implementation towards ecosystem-based management (Pikitch *et al.*, 2004; Long *et al.*, 2015; Hopkins *et al.*, 2011; Tett *et al.*, 2011; Arkema *et al.*, 2016) or ecosystem approaches to management (e.g. Link and Browman, 2017 and references therein; Witherell *et al.*, 2000; Kruse *et al.*, 2009; Kim and Zhang, 2011; Jin *et al.*, 2016). That literature evaluates the extent to which ecosystem-based management is being implemented, both within and across sectors. This Theme Set further contributes to that discussion. Other reports from the MSEAS Symposium are available (Thébaud *et al.*, 2017; Drakou *et al.*, 2017); we do not aim to reiterate them here. Rather, we provide a synthesis of the overarching results from the MSEAS symposium, highlighting recent advances in the study of marine socio-ecological systems. We also provide an introduction to the papers in this Theme Set. We organize this introduction around core themes of the symposium, which also represent common thematic steps in the implementation of integrated ecosystem assessments (Levin *et al.*, 2009, 2014; Dickey-Collas, 2014; Samhouri *et al.*, 2014; Walther and Möllmann, 2014; IPBES, 2015; DePiper *et al.*, 2017; Harvey *et al.*, 2017). Each section that follows is structured with an introductory paragraph (or set of paragraphs) on the topic, highlights of works in this Theme Set, and then transition or synthesis paragraphs as needed. Our aims are to introduce the works that emerged from the symposium and to identify key areas of remaining work.

Identifying needs for managing multiple ocean use sectors—governance, policy, and institutions

One theme of the symposium sought to identify the needs that arise from current and projected marine policy, management and industry developments. It also sought to identify the changes in governance systems and institutions that are in place or under development, particularly those that require jurisdiction and that mandate management of multiple marine sectors. Core questions are: Can governance systems promote greater integration of knowledge systems and ocean management, and if so, how and under what circumstances? And: What information is needed to

inform current and projected policy, management and industry development?

How management systems and institutions use multiple knowledge systems (scientific and technical information, local experiential knowledge, and indigenous knowledge) to make policies and choose management measures in a socio-ecological framework is clearly identified as a key research area (Mackinson, 2001; Olsson and Folke, 2001; Dutra *et al.*, 2015). Additionally, the specifics of *what* information is needed is also recognized as equally important; both in terms of items required to meet governance mandates and items elicited from stakeholder participation (Mardle *et al.*, 2004; Dichmont *et al.*, 2013; Pascoe *et al.*, 2013, 2014). The importance of ecosystem-based management moving from primarily the scientific domain to being more readily adopted by resource managers has been highlighted (Levin *et al.*, 2014; Harvey *et al.*, 2017). How management systems and institutions operate when key knowledge is absent or limited, selecting interim policies and measures when circumstances allow, and filling the knowledge gaps when feasible, is important, given the demand to make decisions with the best scientific information available, even when that is limited.

The paper by Stephenson *et al.* (2017) describes well the range of factors needing to be considered when establishing fisheries policy and management. The summary point of their work is that the management of living marine resources needs to be adopted from a systems perspective. Such a perspective takes into account the multiple considerations required to inform and make management decisions.

It is recognized that there are features of governance systems and institutions that are accepted *de facto* as central to effective governance in a socio-ecological system (Ostrom, 2009). A feature which has been highlighted is stakeholder inclusiveness (Gray, 2005; ICES, 2016; Smith *et al.*, 2017). Another is effective communication and free flow of information both among all stakeholders and expert communities and across sectoral governance authorities (Levin *et al.*, 2014; Link and Browman, 2017). However, there are a large number of ways that governance systems strive to achieve those features and many factors influence their effectiveness in achieving truly integrated decision-making. Governance can achieve greater integration across the different sectoral components of ocean policy, and this is needed, but doing so remains an important challenge. The paper by Smith *et al.* (2017) argues that, in many cases, key impediments to implementing ecosystem-based management are governance and institutional frameworks rather than science. They cite recent work that argues that operational implementation is a management issue rather than being science-limited (Tallis *et al.*, 2010; Levin *et al.*, 2014; Walther and Möllmann, 2014), highlighting the need to continue discussions more broadly than solely among the science community to support integrated ecosystem assessments.

The paper by Steenbergen *et al.* (2017) reinforces this observation with the example of the shrimp fishery in the North Sea. A salient point from Steenbergen et al. explores how well conflicting objectives within the governance system—a problem all too familiar—can determine the success of management measures. Altering the incentives for use and ensuring appropriate treatment of the "common goods" can help mitigate the challenges of these competing objectives, but simply acknowledging multiple objectives remains an important consideration; how to address them is a key challenge.

Two observations related to governance have emerged. First, there is clearly a need for more explicit emphasis on how governance processes address the distribution of benefits and opportunities (Voss *et al.*, 2014; Cormier *et al.*, 2017). There are certainly agreements, institutions and processes that focus on human well-being (Breslow *et al.*, 2016), but they have rarely been explicitly and routinely considered as part of marine governance. Socio-cultural aspects are generally not well covered in policy-making and management planning processes, yet the potential for cultural and personal benefits to accrue from marine uses are greater than typically considered (Kim and Zhang, 2011). To fully realize these socio-cultural benefits, social sciences need to be brought in at the beginning of studies rather than as a later addition to the work (Stephenson *et al.*, 2017). Second, the idea that "governance" is some imutable suite of institutions, with priorities perhaps periodically altered by changes in elected governments, is naïve. Governance is as inherently uncertain and dynamic as the natural system, with displaced peoples, economic down- and up-turns driven by externalities and other factors.The difficulty is amplified by the challenges of pursuing objectives at multiple scales. Individual policies may be targeted to deliver outcomes at specific spatial or temporal scales, yet policies designed to function at different scales necessarily interact in their implementation. Furthermore, governance is not only an act of government(s) as it often is interactive, with many different (public and civil and private) actors involved (Kooiman *et al.*, 2005). It is in this context that integrated governance of marine socio-ecological systems remains a major challenge around the world.

Coupling ecological, economic, and social processes for scenario development and prediction

One theme of the symposium explored scientific advances in the understanding of coupled ecological, economic, and social processes driving the dynamics of marine socio-ecological systems. The literature is replete with methods and tools which may contribute to understanding such processes, ranging from qualitative approaches to quantitative process and empirical model-based approaches (e.g. Pascoe *et al.*, 2009; Smith *et al.*, 2007). Examples include ecological-economic systems dynamics models (Mongruel *et al.*, 2011), the technical mechanics of full system Management Strategy Evaluations (MSEs) (Dichmont *et al.*, 2008; Mapstone *et al.*, 2008; Punt *et al.*, 2016), risk assessments (Sumner *et al.*, 2004; Hobday *et al.*, 2004), prioritization and triaging processes (Pendleton *et al.*, 2015), and similar methods as applied to coupled socio-ecological systems.

The dynamics governing the use of marine resources are not only embedded in ecological systems, but also in associated economic and social systems (Charles, 2001; Ferrol-Schulte *et al.*, 2013). These coupled socio-ecological systems make it challenging to predict consequences of management actions because of interacting non-linear dynamics, self-organization, and cross-scale interactions (Schlüter *et al.*, 2012). The uncertainties that arise from this complexity can pose significant challenges to integrated ecosystem assessments and marine resource management (Fulton *et al.*, 2011). To begin to design strategies to adequately manage socio-ecological systems, a clear understanding of decision-making processes is required that can be directly incorporated in models of individual and collective behavior in socio-ecological systems (Batsleer *et al.*, 2015, 2016; Girardin *et al.*, 2017) as well as the aggregate dynamics within and among resources, actors, and institutions across multiple scales, (Folke *et al.*, 2010). Models of socio-ecological systems thus need to take

explicit account of feedbacks within and between ecological, economic, and social systems, and concurrently account for the uncertainty and stochasticity within and among them.

An important development in coupled socio-ecological system modeling is the increasing formulation of socio-ecological system management issues in terms of MSEs (Smith *et al.*, 2007; Punt *et al.*, 2016). MSEs assess the robustness of alternative management strategies in terms of the likelihood that they will achieve management goals given uncertainties and stochasticities in socio-ecological systems. This involves simulating socio-ecological systems using virtual worlds that mimic system dynamics and produce responses to different future scenarios (Bunnefeld *et al.*, 2011). For MSE to help management achieve its aims, uncertainty needs to be well represented (Punt *et al.*, 2016). This means that uncertainties and stochasticities characteristic of the integrated ecological, economic and social system processes need to be represented as much as possible (Bunnefeld *et al.*, 2011; Fulton *et al.*, 2011).

The paper by Coston-Guarini *et al.* (2017) details new statistical developments for environmental impact assessments that are ecosystem-based. This takes a contrarian view that social and economic aspects are drivers of the ecological system rather than being directly coupled to it. Although the debate over who drives who continues, the importance of delineating cause and effect, particularly in the evaluation of cumulative effects, clearly emerges.

The paper by Zador *et al.* (2017) directly links human dimensions to ecological systems in a common analytical framework using conceptual models. These conceptual models hold promise in eliciting participation from a range of stakeholders (see below) as well as placing all facets of a socio-ecological system in a common context, further facilitating discussion. In many ways, this approach has come to be used as a qualitative MSE, and Zador *et al.* (2017) demonstrate the benefits of doing so for coastal communities. The paper by Boschetti and Andreotta (2017) similarly highlights the value of mental models, noting the utility of this tool in finding common ground in a management context among a diverse set of stakeholders.

Challenges to taking socio-ecological system models to the next level remain. How best to integrate qualitative, analytical, and empirical models of social, economic, and ecological subsystems so as to reveal emergent dynamic properties of the overall system is no trivial exercise. A key challenge in doing so is the diversity and growing complexity of the models being developed, and finding approaches that help address this complexity (Thébaud *et al.*, 2014b). This needs to occur cognizant of the benefits that even simpler, qualitative modeling can provide (Dambacher *et al.*, 2007; Boschetti and Andreotta, 2017; Zador *et al.*, 2017). Although this complexity may be perceived as a hurdle, the benefits of multiple methods and data sources, as well as the efforts currently underway to develop models of intermediate complexity, are quite promising (Plagányi *et al.*, 2014).

Indicators, reference points, and performance evaluation

Another theme of the symposium considered the challenges associated with the identification of adequate indicators, decision criteria, and performance evaluation methods that enable full inclusion of the social and economic dimensions into integrated ecosystem assessments. Key questions remain regarding how to best assess and present the trade-offs associated with alternative scenarios and management strategies.

To be informative, integrated ecosystem assessment indicators, be they empirical or model derived, must integrate across a range of disciplines, processes and conceptual frameworks. As such, there is unlikely to be just one indicator, but rather indicator suites. Indicators must address the practical questions facing policy and blue-growth development in the ocean. When supporting decisions, there is a tension between complex realities vs. simple depictions thereof, along with the need to provide information which is understandable and relevant to multiple parties. Approaches for developing indicators need to include how they can assist in the identification of reference points, and how they can be used to inform performance measures (Sainsbury *et al.*, 2000; Link, 2005). Converting indicators from simple time-series of status and trend into reference points and performance measures is critical to inform and help make key marine resource management decisions towards sustainable blue growth.

A core question is: how do we use the available data to define reference points and assess policy performance? One option is to adopt a pragmatic approach and start by demonstrating the value of more widespread and broader use of extant data (Shin *et al.*, 2010a,b; Large *et al.*, 2013, 2015). The empirical basis for exploring tipping points and thresholds (e.g. Large *et al.*, 2013, 2015; Fay *et al.*, 2013; Samhouri *et al.*, 2014) represents progress towards this objective. Yet, there remains a need to improve our understanding of the relation between human activities, the status of ecosystems, including particular components (e.g. coastal habitats, certain biological guilds, etc.), the status of the services derived from the ecosystems, the impacts on social networks, and where important tipping points emerge (Samhouri *et al.*, 2014; IPBES, 2015; DePiper *et al.*, 2017; Harvey *et al.*, 2017).

The paper by Tam *et al.* (2017) highlights an indicator selection process used by ICES to support one of the European Marine Strategy Framework Directive (Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive) Good Environmental Status criteria. Tam *et al.* (2017) show the range of possible indicators to elucidate food web dynamics, and describe which ones hold promise based on a set of selection criteria. Delineating thresholds, or reference points, based on these indicators remains an important need to better manage the uses of these ecosystems.

Additionally, the empirical understanding of social aspects of coastal communities, although improving, is still falling short of what is needed to fully account for social dimensions in integrated ecosystem assessments (Himes-Cornell and Kasperski, 2015, 2016; Colburn *et al.*, 2016). Coordinated approaches are needed for the collection of social data using a mix of quantitative and qualitative methods, including measures of vulnerability, human well-being, and valuation of the ocean, ocean uses, and ocean goods and services. An important challenge for such monitoring is the need to account explicitly for the distribution—spatially, temporally and across economic and social networks—of benefits and costs to people associated with changes in marine socio-ecological systems and in the ongoing development of the

blue economy. The lack of, and difficulty in, including social, economic data into integrated ecosystem assessments was a common issue that emerged in discussions at MSEAS and is also clear in the literature (Kelble *et al.*, 2013). Simply collecting this range of data can be a daunting, difficult, time-consuming and expensive process. Furthermore, collecting "more" of the social and economic data may result in a tradeoff relative to biologicial or ecological data collection; highlighting the need for coordination when allocating budgets for indicator development. However, understanding the relationships between human uses of the marine environment and marine and coastal ecosystem services is fundamental for integrated ecosystem assessment (Samhouri *et al.*, 2014; DePiper *et al.*, 2017; Harvey *et al.*, 2017; Marshak *et al.*, 2017). Thus, in addition to robust monitoring and data collection systems, research to translate observed components of the socio-ecological system into reference points is critical.

The growing availability of a large number of methods and indicators to support integrated ecosystem assessments is apparent (Levin *et al.*, 2009). Yet, it is acknowledged that there are still very few operational reference points and performance measures internationally, and that thresholds or tipping points for marine socio-ecological systems are far from being generally established (Rice, 2009; Tam *et al.*, 2017), although notable progress is being made (Large *et al.*, 2013, 2015; Fay *et al.*, 2013). The need to account for cumulative effects of multiple uses on ecosystems is also still poorly addressed. In addition, while strong emphasis is often placed on ecological tipping points (and their socio-economic impacts), it is also necessary to consider the possibility of social or economic tipping points (Thébaud *et al.*, 2015). The key observation is that data can be transformed into indicators, from which reference points can be established, either empirically or using models, from which marine management decisions can be informed. In doing so, assessment approaches must enable trade-off evaluation across multiple objectives, that facilitate the development of consensus-based management (Bode *et al.*, 2011; Thébaud *et al.*, 2014a). An example of such an approach, which enables multicriteria assessment as well as accounting for transition processes in marine socio-ecological systems, is co-viability analysis (Cury *et al.*, 2005; Doyen *et al.*, 2013). Other approaches include multi-criteria analysis, the analytic hierarchy process, and goal-programming approaches (Mardle and Pascoe, 1999; Mardle *et al.*, 2000, 2004; Herath, 2004; Pascoe *et al.*, 2009). Collectively, these seek to sharpen the contrast among a range of policy choices relative to tradeoffs among key socio-ecological system considerations.

Participatory assessment processes

Another theme of the symposium focused on the ways in which stakeholder knowledge can become available for integrated ecosystem assessments and can be integrated into decision-making processes. Of particular interest is how the degree of participation may determine the nature and use of the information developed (Soma, 2003; Estvez and Gelchich, 2015; Stephenson *et al.*, 2016). The methods of participatory approaches, such as the processes that enable elicitation of multiple management objectives, are areas of growing importance (Voinov and Bousquet, 2010; Fulton *et al.*, 2013; Dutra *et al.*, 2015; Dichmont *et al.*, 2016; Voinov *et al.*, 2016). The core question which this theme session sought to address was: What are the opportunities and challenges associated with participatory research?

The paper by Morales-Nin *et al.* (2017) describes how a small-scale fishery in the Mediterranean adhered to broader (i.e. national and international) regulatory constraints that were implemented locally by a committee of affected parties. The fishery and its management certainly have room for improvement, but this more collaborative approach to management has reaped many benefits that Morales-Nin *et al.* (2017) highlight. The paper by Steenbergen *et al.* (2017) reinforces the concept that participatory management can help mitigate some conflicts. Additionally, the paper by Boschetti and Andreotta (2017) also reinforces the need for a stakeholder engagement process to achieve common understanding on which to base management decisions.

An important recurring issue is that there is "no one size fits all" when it comes to participatory processes (Gray, 1998; Pita *et al.*, 2012; Leite and Pita, 2016; Stephenson *et al.*, 2016). Certainly there are many ways one can approach engaging stakeholders. A range of methods have been highlighted including fisheries action research, game theory, territory games, experimental economics, Bayesian belief network models, multi-criteria decision analysis and loop analysis (Bailey *et al.*, 2010; Aswani *et al.*, 2013). But a participatory approach that works well in one situation may not necessarily work in another, highlighting the need to remain flexible and have multiple options in the participatory repertoire (Röckmann *et al.*, 2014; Leite and Pita, 2016).

Major challenges in developing participatory research include the difficulty of incorporating the interests of multiple stakeholder groups with interests in the marine environment and how to actively engage and involve a growing number of players interested in the marine sectors, considering also the different levels of power, different perceptions, different knowledge bases, etc. (Ouananian *et al.*, 2012; Kraan *et al.*, 2014). In addition, there is a need to acknowledge the time and resources required to build relationships and trust both between researchers and stakeholders and between different stakeholder groups in participatory research processes. In general, the participatory process often increased mutual respect among sectors and enhanced recognition that "we are all in this together", engendering greater appreciation of the implications of decisions across sectors and greater uptake of decisions (Leite and Pita, 2016).

Summary of lessons learned from practical case studies

A cross-cutting theme of the symposium explored single and multi-sectoral case studies of integrated ecosystem assessments, highlighting experiences when implementation of integrated ecosystem assessments for ecosystem-based management has been attempted. The core question for this theme session was what are the lessons learned from the experience of individuals involved in designing or carrying out these studies? It sought to identify the causes for success and failure in developing such integrated ecosystem assessments that particularly included the human dimension.

Again, the concept of stakeholder inclusion and engagement in the process was identified as a common element important to the success of the process across all the studies (Marshak *et al.*, 2017). For example, the work by Boschetti and Andreotta (2017), Steenbergen *et al.* (2017), and Zador *et al.* (2017) all raise the importance of participatory processes. Although it is difficult to prove that instances where stakeholders were involved early on and extensively in the management process led to better

Table 1. Summary of results from the several theme sessions.

Theme sessions	Core question assessed	Pros	Cons
Identifying needs for managing multiple ocean use sectors—policy, management and industry perspectives	What information is needed to inform policy, management and industry developments?	A lot of work developed in this field; Several needs identified.	Imbalance between domains with large impacts/potential (e.g., tourism, oil and gas) and science; Slow uptake of information from multiple knowledge systems when supporting such work
Governance and institutional frameworks	Can governance systems promote greater integration of knowledge systems and ocean management?	Lots of laws, mandates and conventions; Fair number of legal experts (i.e. lawyers) in attendance at MSEAS; Increasing formal processes for the provision of integrated scientific advice.	Lack of clarity about how to operationalize integrated governance across all sectors; Need for a more explicit emphasis on distribution of benefits and opportunities; Need to recognize that governance is inherently as uncertain as the environment; Often missing political scientists/governance experts in these discusssions.
Coupled ecological, economic and social process understanding of the drivers of change: methods and tools for scenario development and prediction	Can we build scenarios integrating ecological, economic and social dimensions?	Lots of tools for scenario development and prediction exist; Using multiple tools is useful; Key role for scenarios to access different categories of knowledge.	Problems deciding best models and what level of tradeoffs to explore; Difficulty setting scope/scale correctly; Challenge getting models right.
From data to indicators to reference points and performance evaluation	How do we use available data to set reference points and assess policy performance?	Lots of indicators; Increasing wisdom about role of context in defining relevant approaches and methods.	Very few operational RPs and PMs, even thresholds/tipping points; Integrated management will mean multiple indicators each with its own RPs, so need decision-rules that may accommodate different risk tolerance profiles for different properties of SES systems
Participatory assessment processes: opportunities and challenges	What are the opportunities and challenges associated with participatory research?	A lot of work done on this topic and growing; A range of qualitative and quantitative approaches;	Lack of knowledge about how to best integrate participatory research, including how to address incompatabilities from multiple knowledge sources; Problems related to survey fatigue; Need for more input from social sciences (and other sectors) to learn from experience; Need for more methodological synthesis
Integration: lessons learned from practical case studies	What lessons have we learned from practical research experience?	Growing number of case studies and practical examples of integration; Growing standardization of descriptions and comparisons.	Case studies not always fully integrated across key dimensions; Most case studies of integration are issue, sector or even species specific; Missed lessons learned from other disciplines (e.g. forestry, agriculture); Need to improve standardization of lessons learned.

outcomes, it was clear that stakeholder engagement helped to broaden the treatment of societal goals and led to improved overall metrics of success. For example, studies show that when moving from a focus solely on total revenues to the fishing fleet, following subsequent engagement of stakeholders, individuals involved became more concerned about the distribution of those revenues, as well as other social aspects of impacts on fishing communities that might be affected by management decisions (Stokes *et al.*, 2006).

It is clear that there are a variety of tools being implemented to integrate the human dimension into integrated ecosystem assessments. These range from community organizing tools such as co-operative formation to community assessment tools such as multi-criteria decision analysis, loop analysis, choice modelling, and Bayesian network analysis, and range from being quantitative to qualitative. The mental or conceptual modelling described in Zador *et al.* (2017) and Boschetti and Andreotta (2017) illustrate these qualitative approaches, similar to the loop analysis that Dambacher *et al.* (2007) used in coastal multiple use management. As more examples are developed it will be helpful to start evaluating the variety of approaches being employed and developing a set of best practices for use of these tools.

Smith *et al.* (2017) describe what is arguably one of the most advanced attempts to implement fully integrated, multi-sector, ecosystem-based management. The major steps outlined in their work reinforce the common steps codified for most compilations of integrated ecosystem assessment best practices (Levin *et al.*, 2009, 2014; Dickey-Collas, 2014; Samhouri *et al.*, 2014; Walther and Möllmann, 2014; Harvey *et al.*, 2017), and again loosely reflect the structure of the MSEAS meeting. The many Australian examples given by Smith *et al.* (2017) highlight the importance of including clearly identified needs and objectives, stakeholder

ownership, well-defined governance frameworks, and scientific tools to deal with conflicts and trade-offs in ongoing discussions of the blue economy.

There is still a long way to go before we see end-to-end integrated ecosystem assessments inclusive of all the major current and potential ocean use sectors that also encompass multiple aspects of human dimensions (Link and Browman, 2017; Marshak *et al.*, 2017). But from the MSEAS meeting, and the papers in this Theme Set, it is clear that progress is being made and we are developing useful information on all aspects of marine ecosystems, particularly including the human dimension, that can inform management now as we continue to conduct integrated ecosystem assessments (Thébaud *et al.* 2017).

Conclusions

There are multiple dimensions to integrated ecosystem assessments, and even more when considering the many facets of explicitly including the human dimension, and yet more when attempting to integrate across multiple ocean-use sectors. A lot of the work presented in the Theme Set and at the MSEAS meeting was still very fishery and conservation centric. How to involve other sectors remains an important challenge. Additionally, what is the right mix for integrating across these many dimensions, especially with respect to complexity, models, the various disciplines represented (such that we don't lose their distinctiveness while still integrating), governance, and scale? Addressing issues such as these are necessary to advance the ecosystem approach to management and to facilitate sustainable blue growth. As noted by Marshak *et al.* (2017), we still very much need to address such structural impediments to ecosystem-based management.

Understanding the myriad dynamics of marine socio-ecological systems remains an exciting area of research. Taking a reductionist approach helps with mechanisms and details, but has limits when the intent is to identify systemic solutions—and when we do employ reductionistic methods, we often drop the human dimension elements first. Alternatively, inclusivity and systems-thinking encourages the consideration of different disciplines from the start (Charles, 2001; Meadows, 2008). For instance, copious and extant tools, indicators and information are now available from several interdisciplinary integrated ecosystem assessment efforts. Maintaining such an emphasis and fostering interdisciplinary discussions and collaborations is warranted (Drakou *et al.*, 2017). The value of the MSEAS meeting, and we hope this Theme Set, is that in getting the different disciplines together to talk is helpful and leads to better use of multiple models, getting past disciplinary jargon, and increasing the number of case studies that incorporate human dimensions and thereby improve marine resource management.

From the symposium and articles in this Theme Set, several challenges have emerged (Table 1). Addressing governance complexity, especially with respect to cumulative effects and cross-jurisdictional uses for fully integrated ecosystem-based management, remains a challenge. Similarly, promoting sufficient governance adaptability to respond in coherent ways across sectoral jurisdicitons also remains a challenge. From an implementation perspective, operationalizing research advances into appropriate management venues can be a significant hurdle. From a research perspective, codifying the value and rewards for interdisciplinary work is needed to improve incentives for interdisciplinary research, such that governments, universities, and NGOs may wish to create and fund more professional positions focused on inter-disciplinary programs. Of course, adapting to some of the major challenges facing society (e.g. global climate change, environmental degradation) remains an underlying consideration for both the natural and human systems as blue growth continues.

Our sense from the MSEAS meeting and discussions with colleagues around the globe is that human dimensions not only need to, but are effectively beginning to be considered more frequently in integrated ecosystem assessments (DePiper *et al.*, 2017). More effective incorporation of the human dimension into marine assessment and management processes is crucial for achieving equitable outcomes for the blue economy (Burgess *et al.*, 2017; Singh *et al.*, 2017). There is recognition that such broader discussions are occurring and that they are leading to implementing more effective solutions towards sustainable and equitable marine ecosystem-based management (Thébaud *et al.*, 2017).

We conclude by observing from the case studies identified above that ocean uses and resources are managed effectively in some places. In each instance, some form of integration is apparent, and some inclusion of human dimensions is also apparent. As we continue to seek sustainable blue growth to support the global economy, it would be prudent to consider these factors more deliberately as we move forward.

References

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

Aswani, S., Gurney, G. G., Mulville, S., Matera, J., and Gurven, M. 2013. Insights from experimental economics on local cooperation in a small-scale fishery management system. Global Environmental Change, 23: 1402–1409.

Bailey, M., Rashid Sumaila, U., and Lindroos, M. 2010. Application of game theory to fisheries over three decades. Fisheries Research, 102: 1–8.

Batsleer, J., Hamon, K. G., van Overzee, H. M. J., Rijnsdorp, A. D., and Poos, J. J. 2015. High-grading and over-quota discarding in mixed fisheries. Reviews in Fish Biology and Fisheries, 25: 715–736.

Batsleer, J., Rijnsdorp, A. D., Hamon, K. G., van Overzee, H. M. J., and Poos, J. J. 2016. Mixed fisheries management: Is the ban on discarding likely to promote more selective and fuel efficient fishing in the Dutch flatfish fishery? Fisheries Research, 174: 118–128.

Begg, G. A., Stephenson, R. L., Ward, T. M., Gillanders, B. M., and Smith, A. D. 2015. Practical steps to implementation of integrated marine management. SARDI Research Report, 848: 165.

Bode, M., Probert, W., Turner, W. R., Wilson, K. A., and Venter, O. 2011. Conservation planning with multiple organizations and objectives. Conservation Biology, 25: 295–304.

Boschetti, F., and Andreotta, M. 2017. Mental models of communication and engagement in marine projects. ICES Journal of Marine Science, 74: 2034–2039.

Breslow, S. J., Sojka, B., Barnea, R., Basurto, X., Carothers, C., Charnley, S., Coulthard, S., Dolšak, N., Donatuto, J., García-Quijano, C., and Hicks, C. C. 2016. Conceptualizing and operationalizing human wellbeing for ecosystem assessment and management. Environmental Science and Policy, 66: 250–259.

Bunnefeld, N., Hoshino, E., and Milner-Gulland, E. J. 2011. Management strategy evaluation: a powerful tool for conservation? Trends in Ecology and Evolution, 26: 441–447.

Burgess, M. G., Clemence, M., McDermott, G. R., Costello, C., and Gaines, S. D. 2017. Five rules for pragmatic blue growth. Marine Policy. doi:10.1016/j.marpol.2016.12.005.

Charles, A. 2001. Sustainable Fishery Systems. Wiley-Blackwell, Oxford. 384 pp.

Colburn, L. L., Jepson, M., Weng, C., Seara, T., Weiss, J., and Hare, J. A. 2016. Indicators of climate change and social vulnerability in fishing dependent communities along the Eastern and Gulf Coasts of the United States. Marine Policy, 74: 323–333.

Cormier, R., Kelble, C. R., Anderson, M. R., Allen, J. I., Grehan, A., and Gregersen, O. 2017. Moving from ecosystem-based policy objectives to operational implementation of ecosystem-based management measures. ICES Journal of Marine Science, 74: 406–413.

Coston-Guarini, J., Guarini, J.-M., Edmunds, J., Hinz, S., Wilson, J., and Chauvaud, L. 2017. A roadmap for a quantitative, ecosystem-based environmental impact assessment. ICES Journal of Marine Science, 74: 2012–2023.

Cury, P., Mullon, C., Garcia, S., and Shannon, L. J. 2005. Viability theory for an ecosystem approach to fisheries. ICES Journal of Marine Science, 62: 577–584.

Dambacher, J. M., Brewer, D. T., Dennis, D. M., Macintyre, M., and Foale, S. 2007. Qualitative modelling of gold mine impacts on Lihir Island's socioeconomic system and reef-edge fish community. Environmental Science and Technology, 41: 555–562.

DePiper, G. S., Gaichas, S. K., Lucey, S. M., Pinto da Silva, P., Anderson, M. R., Breeze, H., Bundy, A. *et al.* 2017. Operationalizing integrated ecosystem assessments within a multidisciplinary team: lessons learned from a worked example. ICES Journal of Marine Science, doi:10.1093/icesjms/fsx038.

Díaz, S., Demissew, S., Joly, C., Lonsdale, W. M., Larigauderie, A., Perrings, C. *et al.* 2015. A rosetta stone for nature's benefits to people. PLOS Biology, 13: e1002040.

Dichmont, C. M., Deng, A., Punt, A. E., Ellis, N., Venables, W. N., Kompas, T., Ye, Y., Zhou, S., and Bishop, J. 2008. Beyond biological performance measures in management strategy evaluation: bringing in economics and the effects of trawling on the benthos. Fisheries Research, 94: 238–250.

Dichmont, C. M., Pascoe, S., Jebreen, E., Pears, R., Brooks, K., and Perez, P. 2013. Choosing a fishery's governance structure using data poor methods. Marine Policy, 37: 123–131.

Dichmont, C. M., Dutra, L. X. C., Owens, R., Jebreen, E., Thompson, C., Deng, R. A. *et al.* 2016. A generic method of engagement to elicit regional coastal management options. Ocean and Coastal Management, 124: 22–32.

Dickey-Collas, M. 2014. Why the complex nature of integrated ecosystem assessments requires a flexible and adaptive approach. ICES Journal of Marine Science, 71: 1174–1182.

Doyen, L., Cissé, A., Gourguet, Mouysset, S., Hardy, P. Y., Béné, C., Blanchard, F., Jiguet, F., Pereau, J. C., and Thébaud, O. 2013. Ecological-economic modelling for the sustainable management of biodiversity. Computational Management Science, 10: 353–364.

Drakou, E., Kermagoret, C., Comte, A., Trapman, B., and Rice, J. 2017. Shaping the future of marine socio-ecological systems research: when early-career researchers meet the seniors. ICES Journal of Marine Science, 74: 1957–1964.

Dutra, L. X. C., Thébaud, O., Boschetti, F., Smith, A. D. M., and Dichmont, C. M. 2015. Key issues and drivers affecting coastal and marine resource decisions: participatory management strategy evaluation to support adaptive management. Ocean and Coastal Management, 116: 382–395.

Estévez, R. A., and Gelcich, S. 2015. Participative multi-criteria decision analysis in marine management and conservation: research progress and the challenge of integrating value judgments and uncertainty. Marine Policy, 61: 1–7.

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

Ferrol-Schulte, D., Wolff, M., Ferse, S., and Glaser, M. 2013. Sustainable Livelihoods Approach in tropical coastal and marine social-ecological systems: a review. Marine Policy, 42: 253–258.

Folke, C., Carpenter, S. R., Walker, B., Scheffer, M., Chapin, T., and Rockström, J. 2010. Resilience thinking: integrating resilience, adaptability and transformability. Ecology and Society, 15: 20.

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

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

Girardin, R., Hamon, K. G., Pinnegar, J., Poos, J. J., Thébaud, O., Tidd, A., Vermard, Y., and Marchal, P. 2017. Thirty years of fleet dynamics modelling using discrete-choice models: what have we learned? Fish and Fisheries, 18: 638–655.

Gray, T. S. (Ed.). 1998. The Politics of Fishing. Palgrave Macmillan UK, London, 258 pp.

Gray, T. S. 2005. Participation in Fisheires Governance. Springer

Harvey, C. J., Kelble, C. R., and Schwing, F. B. 2017. Implementing "the IEA": using integrated ecosystem assessment frameworks, programs, and applications in support of operationalizing ecosystem-based management. ICES Journal of Marine Science, 74: 398–405.

Herath, G. 2004. Incorporating community objectives in improved wetland management: the use of the analytic hierarchy process. Journal of Environmental Management, 70: 263–273.

Himes-Cornell, A., and Kasperski, S. 2015. Assessing climate change vulnerability in Alaska's fishing communities. Fisheries Research, 162: 1–11.

Himes-Cornell, A., and Kasperski, S. 2016. Using socioeconomic and fisheries involvement indices to understand Alaska fishing community well-being. Coastal Management, 44: 36–70.

Hobday, A. J., Smith, A., and Stobutzki I., 2004. Ecological risk assessment for Australian Commonwealth fisheries, final report. Report R01/0934 to the Australian Fisheries Management Authority, Canberra, Australia. 72 pp. http://www.afma.gov.au/research/reports/2004/r01_0934.pdf.

Hopkins, T. S., Bailly, D., and Støttrup, J. G. 2011. A systems approach framework for coastal zones. Ecology and Society, 16: 25.

ICES. 2016. AORAC-SA FAO Workshop: Making The Ecosystem Approach Operational, 21-22 January, Copenhagen, DK, 55 pp.

Inniss, L., Simcock, A., Ajawin, A. Y. *et al.* 2016. The first global integrated marine assessment; world ocean assessment. United Nations, New York.

IPBES. 2015. Guide on production and integration of assessments from and across all scales. http://www.ipbes.net/sites/default/files/downloads/IPBES-4-INF-9_EN_0.pdf.

Jin, D., DePiper, G., and Hoagland, P. 2016. Applying portfolio management to implement Ecosystem-Based Fishery Management (EBFM). North American Journal of Fisheries Management, 36: 652–669.

Kelble, C. R., Loomis, D. K., Lovelace, S., Nuttle, W. K., Ortner, P. B., Fletcher, P., Cook, G. S. *et al.* 2013. The EBM-DPSER conceptual model: integrating ecosystem services into the DPSIR framework. PLoS One 8: e70766.

Kim, D. H., and Zhang, C. I. 2011. Developing socioeconomic indicators for an ecosystem-based fisheries management approach: an application to the Korean large purse seine fishery. Fisheries Research, 112: 134–139.

Kittinger, J., Finkbeiner, E., Ban, N., Broad, K., Cass, M., Cinner, J., Gelcich, S., Cornwell, M., Koehn, Z., Basurto, X. *et al.* 2013. Emerging frontiers in social-ecological systems research for sustainability of small scale fisheries. Current Opinion in Environmental Sustainability, 5: 352–357.

Kooiman, J., Bavinck, M., Jentoft, S., and Pullin, R. 2005. Fish for LIFE: INTERACTIVE GOVERNANCE for Fisheries. Amsterdam University Press, Amsterdam, 427 pp.

Kraan, M., Hendriksen, A., Van Hoof, L., van Leeuwen, J., and Jouanneau, C. 2014. How to dance? The tango of stakeholder involvement in marine governance research. Marine Policy, 50B: 347–352.

Kruse, G. H., Ishida, Y., Perry, E. A., Radchenko, V. I., and Zhang, C. I. Eds. 2009. Ecosystem Approach to Fisheries: Improvements on traditional management for declining and depleted stocks. Fisheries Research, 100: 1–98.

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

Large, S. I., Fay, G., Friedland, K. D., and Link, J. S. 2015. Quantifying patterns of change in ecosystem response to multiple pressures. PLoS One, 10: e0119922.

Leite, L., and Pita, C. 2016. Review of participatory fishery management arrangements in the European Union. Marine Policy, 74: 268–278.

Levin, P. S., Fogarty, M. J., Murawski, S. A., and Fluharty, D. 2009. Integrated ecosystem assessments: developing the scientific basis for ecosystem-based management of the ocean. PLoS Biology, 7: e1000014.

Levin, P. S., Kelble, C. R., Shuford, R., Ainsworth, C., deReynier, Y., Dunsmore, R., Fogarty, M. J., Holsman, K., Howell, E., Monaco, M. *et al.* 2014. Guidance for implementation of integrated ecosystem assessments: a US perspective. ICES Journal of Marine Science, 71: 1198–1204.

Lillebø, A., Pita, C., Garcia Rodrigues, J., Ramos, S., and Villasante, S. 2017. How can marine ecosystem services support the Blue Growth agenda? Marine Policy, 81: 132–142.

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

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

Link, J. S., and Browman, H. I. 2017. Operationalizing and implementing ecosystem-based management. ICES Journal of Marine Science, 74: 379–381.

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

Mackinson, S. 2001. Integrating local and scientific knowledge: an example in fisheries science. Environmental Management, 27: 533–545.

Mapstone, B. D., Little, L. R., Punt, A. E., Davies, C. R., Smith, A. D. M., Pantus, F., McDonald, A. D., Williams, A. J., and Jones, A. 2008. Management strategy evaluation for line fishing in the Great Barrier Reef: balancing conservation and multi-sector fishery objectives. Fisheries Research, 94: 315–329.

Mardle, S., and Pascoe, S. 1999. A review of applications of multiple-criteria decision-making techniques to fisheries. Marine Resource Economics, 14: 41–63.

Mardle, S., Pascoe, S., Tamiz, M., and Jones, D. 2000. Resource allocation in the North Sea demersal fisheries: a goal programming approach. Annals of Operations Research, 94: 321–342.

Mardle, S., Pascoe, S., and Herrero, I. 2004. Management objective importance in fisheries: an evaluation using the analytic hierarchy process (AHP). Environmental Management, 33: 1–11.

Marshak, A. R., Link, J. S., Shuford, R., Monaco, M. C., Johannesen, E., Bianchi, G., Anderson, M. R., Losen, E., Smith, D. C., Schmidt, J., and Dickey-Collis, M. 2017. International perceptions of an integrated, multi-sectoral ecosystem approach to management. ICES Journal of Marine Science, 74: 414–420.

Meadows, D. H. 2008. Thinking in Systems: A Primer. Chelsea Green, 240 pp.

Mongruel, R., Prou, J., Ballé-Béganton, J., Lample, M., Vanhoutte-Brunier, A., Réthoret, H., Pérez Agúndez, J., Vernier, F., Bordenave, P., and Bacher, C. 2011. Modeling soft institutional change and the improvement of freshwater governance in the coastal zone. Ecology and Society, 16: 15.

Morales-Nin, B., Grau, A. M., Aguilar, J. S., Gil, M., del, M., and Pastor, E. 2017. Balearic Islands boat seine fisheries: the transparent goby fishery an example of co-management. ICES Journal of Marine Science, 74: 2053–2058.

OECD. 2016. The Ocean Economy in 2030. OECD Publishing, Paris.

Olsson, P., and Folke, C. 2001. Local ecological knowledge and institutional dynamics for ecosystem management: A study of Lake Racken watershed, Sweden. Ecosystems, 4: 85–104.

Ommer, R., Perry, R.I., Cochrane, K.L., Curry P. (Ed.). 2011. World Fisheries: a social-ecological analysis. Fish and Aquatic Resources series 14. Wiley-Blackwell, Chichester. 418 pp.

Ostrom, E. 2009. A general framework for analyzing sustainability of socialecological systems. Science, 325: 419–422.

Ounanian, K., Delaney, A., Raakjaer, J., and Ramirez-Monsalve, P. 2012. On Unequal Footing: Stakeholders' perspectives on the Marine Strategy Framework Directive as a mechanism of the ecosystem-based approach to marine management. Marine Policy, 36: 658–666.

Pascoe, S., Bustamante, R., Wilcox, C., and Gibbs, M. 2009. Spatial fisheries management: a framework for multi-objective qualitative assessment. Ocean and Coastal Management, 52: 130–138.

Pascoe, S., Dichmont, C. M., Brooks, K., Pears, R., and Jebreen, E. 2013. Management objectives of Queensland fisheries: putting the horse before the cart. Marine Policy, 37: 115–122.

Pascoe, S., Brooks, K., Cannard, T., Dichmont, C. M., Jebreen, E., Schirmer, J., and Triantafillos, L. 2014. Social objectives of fisheries management: what are managers' priorities? Ocean and Coastal Management, 98: 1–10.

Pendleton, L., Mongruel, R., Beaumont, N., Hooper, T., and Charles, M. 2015. A triage approach to improve the relevance of marine ecosystem services assessments. Marine Ecological Progress Series, 530: 183–193.

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

Pita, C., Chuenpagdee, R., and Pierce, G. J. 2012. Participatory issues in fisheries governance in Europe. Management of Environmental Quality: An International Journal, 23: 347–361.

Plagányi, E. E., Punt, A. E., Hillary, R., Morello, E. B., Thébaud, O., Hutton, T., Pillans, R. D. *et al.* 2014. Multispecies fisheries management and conservation: Tactical applications using models of intermediate complexity. Fish and Fisheries, 15: 1–22.

Punt, A. E., Butterworth, D. S., de Moor, C. L., De Oliveira, J. A. A., and Haddon, M. 2016. Management strategy evaluation: best practices. Fish and Fisheries, 17: 303–334.

Rice, J. C. 2009. A generalization of the three-stage model for advice using the precautionary approach in fisheries, to apply broadly to ecosystem properties and pressures. ICES Journal of Marine Science, 66: 433–444.

Rice, J., and Garcia, S. 2011. Fisheries, food security, climate change, and biodiversity: characteristics of the sector and perspectives on emerging issues. ICES Journal of Marine Science, 68: 1343–1353.

Röckmann, C., van Leeuwen, J., Goldsborough, D., Kraan, M., and Piet, G. 2014. The interaction triangle as a tool for understanding stakeholder interactions in marine ecosystem based management. Marine Policy, 52: 155–162.

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

Samhouri, J., Haupt, A., Levin, P., Link, J., and Shuford, R. 2014. Lessons learned from developing integrated ecosystem assessments to inform marine ecosystem-based management in the USA. ICES Journal of Marine Science, 71: 1205–1215.

Schlüter, M., McAllister, R. R. J., Arlinghaus, R., Bunnefeld, N., Eisenack, K., Hölker, F., Milner-Gulland, E. J., Müller, B., Nicholson, E., Quaas, M., and Stöven, M. 2012. New horizons for managing the environment: A review of coupled social-ecological systems modeling. Natural Resource Modeling, 25: 219–272.

Shin, Y.-J., Shannon, L. J., Bundy, A., Coll, M., Blanchard, J. L., Borges, M.-F., Cotter, J., Cury, P. M., Heymans, J. J., Jouffre, D., Link, J. S., Möllmann, C., Ojaveer, H., Abdallahi, K. O. M., Rochet, M.-J., and Yemane, D. 2010a. Using indicators for evaluating, comparing and communicating the ecological status of exploited marine ecosystems. Part 2: setting the scene. ICES Journal of Marine Science, 67: 692–716.

Shin, Y.-J., Bundy, A., Shannon, L. J., Simier, M., Coll, M., Fulton, E. A., Link, J. S., Jouffre, D., Ojaveer, H., Mackinson, S., Heymans, J. J., and Raid, T. 2010b. Can simple be useful and reliable? Using ecological indicators for representing and comparing the states of marine ecosystems. ICES Journal of Marine Science, 67: 717–731.

Singh, G. G., Cisneros-Montemayor, A. M., Swartz, W., Cheung, W., Guy, J. A., Kenny, T.-A., McOwen, C. J., Asch, R., Geffert, J. L., Wabnitz, C. C. C., Sumaila, R. *et al.* 2017. A rapid assessment of co-benefits and trade-offs among Sustainable Development Goals. Marine Policy, doi:10.1016/j.marpol.2017.05.030.

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

Smith, D. C., Fulton, E., Apfel, P., Cresswell, I., Gillanders, B., Haward, M., Sainsbury, K., Smith, A. D. M., Vince, J., and Ward, T. 2017. Implementing marine Ecosystem Based Management: Lessons from Australia. ICES Journal of Marine Science, 74: 1990–2003.

Soma, K. 2003. How to involve stakeholders in fisheries management—a country case study in Trinidad and Tobago. Marine Policy, 27: 47–58.

Steenbergen, J., Trapman, B. K., Steins, N. A., and Poos, J. J. 2017. The commons tragedy in the North Sea brown shrimp fishery: how horizontal institutional interactions inhibit a self-governance structure. ICES Journal of Marine Science, 74: 2004–2011.

Stephenson, R. L., Paul, S., Pastoors, M., Kraan, M., Holm, P., Wiber, M., Mackinson, S., Dankel, D., Brooks, K., and Benson, A. 2016. Integrating fishers' knowledge research in science and management. ICES Journal of Marine Science, 73: 1459–1465.

Stephenson, R., Benson, A., Brooks, K., Charles, A., Degnbol, P., Dichmont, C., Kraan, M., Pascoe, S., Paul, S., Rindorf, A., and Wiber, M. 2017. Practical steps toward integrating economic, social and institutional elements in fisheries policy and management. ICES Journal of Marine Science, 74: 1981–1989.

Stokes, K. E., O'Neill, K. P., Montgomery, W. I., Dick, J. T. A., Maggs, C. A., and McDonald, R. A. 2006. The importance of stakeholder engagement in invasive species management: A cross-jurisdictional perspective in Ireland. Biodiversity and Conservation, 15: 2829–2852.

Sumner, J., Ross, T., and Ababouch, L. 2004. Application of Risk Assessment in the Fish Industry. FAO Fisheires Technical Paper 442.

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

Tam, J., Link, J., Rossberg, A., Rogers, S., Levin, P., Rochet, M.-J., Bundy, A. *et al.* 2017. Towards ecosystem-based management: identifying operational food-web indicators for marine ecosystems. ICES Journal of Marine Science, 74: 2040–2052.

Tett, P., Sandberg, A., and Mette, A. 2011, Sustaining Coastal Zone Systems. Dunedin Academic Press Ltd., Edinburgh, 173 pp.

Thébaud, O., Ellis, N., Little, L. R., Doyen, L., and Marriott, R. J. 2014a. Viability trade-offs in the evaluation of strategies to manage recreational fishing in a marine park. Ecological Indicators, 46: 59–69.

Thébaud, O., Doyen, L., Innes, J., Lample, M., Macher, C., Mahévas, S., Mullon, C. *et al.* 2014b. Building ecological-economic models and scenarios of marine resource systems: Workshop report. Marine Policy, 43: 382–386.

Thébaud, O., Boschetti, F., Jennings, S., Smith, A. D. M., and Pascoe, S. 2015. Of sets of offsets: cumulative impacts and strategies for compensatory restoration. Ecological Modelling, 312: 114–124.

Thébaud, O., Link, J. S., Kohler, B., Kraan, M., López, R., Poos, J. J., Schmidt, J. O., and Smith, D. C. 2017. Managing marine socio-ecological systems: picturing the future. ICES Journal of Marine Science, 74: 1965–1980.

UNEP. 2006 Marine and coastal ecosystems and human well-being: A synthesis report based on the findings of the Millennium Ecosystem Assessment. UNEP. 76 pp.

United Nations. 2016. World Ocean Assessment I. United Nations, New York. http://www.un.org/Depts/los/global_reporting/WOA_RegProcess.htm.

Voinov, A., and Bousquet, F. 2010. Modelling with stakeholders. Environmental Modeling and Software, 25: 1268–1281.

Voinov, A., Kolagani, N., McCall, M., Glynn, P. D., Kragt, M. E., Ostermann, F. O., Pierce, S. A., and Ramu, P. 2016. Modelling with stakeholders – next generation. Environmental Modeling and Software, 77: 196–220.

Voss, R., Quaas, M. F., Schmidt, J., and Hoffmann, J. 2014. Regional trade-offs from multi-species maximum sustainable yield (MMSY) management options. Marine Ecology Progress Series, 498: 1–12.

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

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

Zador, S., Gaichas, S., Kasperski, S., Ward, C., Blake, R., Ban, N., Himes-Cornell, A., and Koehn, Z. 2017. Linking ecosystem processes to communities of practice through commercially fished species in the Gulf of Alaska. ICES Journal of Marine Science, 74: 2024–2033.