Challenges, insights and perspectives associated with using social-ecological science for marine conservation

Pierre Leenhardt, Lida Teneva, Stuart Kininmonth, Emily Darling, Sarah Cooley, Joachim Claudet

Ocean & Coastal Management 115 (2015) 49–60

Contents lists available at ScienceDirect

Ocean & Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Challenges, insights and perspectives associated with using social-ecological science for marine conservation

Pierre Leenhardt [a, b, *], Lida Teneva [c], Stuart Kininmonth [d], Emily Darling [e], Sarah Cooley [f], Joachim Claudet [a, b]

[a] National Center for Scientific Research, CRIOBE, USR 3278 CNRS-EPHE-UPVD, 66860 Perpignan, France
[b] LABEX CORAIL, France
[c] Conservation International, Betty and Gordon Moore Center for Science and Oceans, 7192 Kalaniana'ole Hwy, Ste. G-230, Honolulu, HI 96825, USA
[d] Stockholm Resilience Centre, Stockholm University, Kräftriket 2B, SE-106 91 Stockholm, Sweden
[e] Biology Department, University of North Carolina, Chapel Hill, NC 25799, USA
[f] Ocean Conservancy, 1300 19th St., NW Suite 800, Washington, DC 20036, USA

ARTICLE INFO

Article history:
Received 28 November 2014
Received in revised form
15 April 2015
Accepted 28 April 2015

Keywords:
Social-ecological systems
Sustainability science
Conservation
Natural resource management

ABSTRACT

Here, we synthesize conceptual frameworks, applied modeling approaches, and as case studies to highlight complex social-ecological system (SES) dynamics that inform environmental policy, conservation and management. Although a set of "good practices" about what constitutes a good SES study are emerging, there is still a disconnection between generating SES scientific studies and providing decision-relevant information to policy makers. Classical single variable/hypothesis studies rooted in one or two disciplines are still most common, leading to incremental growth in knowledge about the natural or social system, but rarely both. The recognition of human dimensions is a key aspect of successful planning and implementation in natural resource management, ecosystem-based management, fisheries management, and marine conservation. The lack of social data relating to human-nature interactions in this particular context is now seen as an omission, which can often erode the efficacy of any resource management or conservation action. There have been repeated calls for a transdisciplinary approach to complex SESs that incorporates resilience, complexity science characterized by intricate feedback interactions, emergent processes, non-linear dynamics and uncertainty. To achieve this vision, we need to embrace diverse research methodologies that incorporate ecology, sociology, anthropology, political science, economics and other disciplines that are anchored in empirical data. We conclude that to make SES research most useful in adding practical value to conservation planning, marine resource management planning processes and implementation, and the integration of resilience thinking into adaptation strategies, more research is needed on (1) understanding social-ecological landscapes and seascapes and patterns that would ensure planning process legitimacy, (2) costs of transformation (financial, social, environmental) to a stable resilient social-ecological system, (3) overcoming place-based data collection challenges as well as modeling challenges.

1. Introduction

There are a variety of conceptual models of social-ecological systems (SESs) that depict and characterize human-nature interactions in integrative ways (Young et al., 2006). These models are increasingly used in natural resource management and often in marine conservation (Xu and Marinova, 2013; Kittinger et al., 2013). As anthropogenic pressures have increased across all ecosystems, environmental sciences have undergone a paradigm shift in recent years, recognizing the crucial need to take into account human–nature relationships to better inform and guide conservation and management (Mace, 2014).

Consequently, SES studies have expanded dramatically during the last decade (Young, 2006; Xu and Marinova, 2013), revealing a growing interest from researchers and the public at large to understand SES dynamics and the sustainability of human-nature

* Corresponding author. National Centre for Scientific Research, CRIOBE, USR 3278 CNRS-EPHE-UPVD, 66860 Perpignan, France.
E-mail address: pierre.leenhardt@gmail.com (P. Leenhardt).

http://dx.doi.org/10.1016/j.ocecoaman.2015.04.018

interactions in terrestrial and marine environments (Liu et al., 2007a; Cinner et al., 2009b; Chapin et al., 2010; Diaz et al., 2011). Major scientific initiatives such as the Resilience Alliance (Folke et al., 2004), the Millennium Ecosystem Assessment (MA, 2005) and the establishment of the Sustainable Development Goals (SDGs) have provided comprehensive conceptual frameworks which link social and ecological systems. SES theories are based largely on the concept of resilience thinking (Gunderson and Holling, 2002; Hughes et al., 2005), which explores the dynamics and the organization of SESs, and their policy implications of SES contexts (Folke et al., 2004; Folke, 2006; Fischer et al., 2009; Deppisch and Hasibovic, 2011). For example, the Resilience Alliance has investigated SESs through a transdisciplinary lens with insights from complexity science (Holling, 2001; Berkes et al., 2003). Policy-relevant initiatives such as the Millennium Ecosystem Assessment (MEA) and Sustainable Development Goals (SDGs) are catalyzing meaningful research on ecosystem services and human well-being to fill a knowledge gap on the dynamics of human-nature interactions in SESs (MA, 2005). New scientific fields such as sustainability science (Kates, 2001, 2011; Clark, 2007; Bettencourt and Kaur, 2011) or land change science (Turner et al., 2007) have emerged from this thinking at the same time and also provided research and methodological guidelines for investigating SESs (Biggs et al., 2012a).

From this theoretical understanding, applied social-ecological science can provide case study approaches to investigations of place-based issues and can inform broader conservation and management (Parrott and Chion, 2012; Schlüter and Hinkel, 2014; Lowe et al., 2014). Ocean and coastal environments are complex adaptive SESs where social relationships of stewardship are diverse and resource use is most often unsustainable (Cinner et al., 2009b; Cinner, 2011, 2014; Kittinger et al., 2012, 2013). In marine environments, successful resource planning, therefore, requires diverse datasets and tools (Kittinger et al., 2014). Understanding how such complex adaptive systems are structured, evolve through time, respond to different pressures (e.g. environmental stressors, policy decisions, or management actions), and provide ecosystem services important for human wellbeing is crucial for social-ecological theory to inform marine conservation and management that produces long-term benefits for nature and people.

In this paper, we review the challenges of evolving social-ecological science towards applied outcomes to support resource management and marine conservation. We illustrate those challenges with insights coming from three distinct case studies. The paper has two main goals: 1) to elucidate the challenges of integrating social-ecological science into practical uses for natural resource management, conservation planning, and policy-making in marine ecosystems, and 2) to provide insights on how emerging transdisciplinary social-ecological science can best become an essential and practical decision-support tool in ocean spatial planning and conservation practice with clear linkages to how effective strategies for uptake into management and conservation can be developed. In effect, by unraveling marine environments as intricate peopled seascapes, social-ecological studies and resilience experts can unveil overlooked linkages in marine systems and provide paths to solutions (Kittinger et al., 2014). We base our review on a symposium workshop held during the International Marine Conservation Congress in 2014, as well as on emerging new research on the importance of social data in ocean and coastal environments.

2. The social-ecological challenges of marine conservation

2.1. From a transdisciplinary science to an interdisciplinary management

Transdisciplinarity – a research strategy that crosses disciplinary boundaries to create a holistic approach - is a prerequisite for investigations of SES properties or dynamics. For many years, the need for transdisciplinary collaborations in natural resource management and especially in marine conservation science had been underestimated (Christie, 2011; Fisher, 2012). However, complex marine conservation issues proved difficult to explore through the lens of a single discipline (Lade et al., 2013). Today, it is widely acknowledged that we need integrative approaches involving both social and natural sciences in order to capture a complete picture of complex SESs (Liu et al., 2007a; Ostrom, 2009; Carpenter et al., 2009). For example, transdisciplinary collaborations across biology, ecology, economics, geography, history, law, political science, anthropology, psychology, sociology and computer science can provide fundamental knowledge support for effective marine conservation and management (Carson et al., 2006; Clark, 2007; McDonald et al., 2008). However, while transdisciplinarity needs to be an academic endeavor, it is clear that interdisciplinarity is much more achievable in a management context (Fig. 1).

'Social-ecological system' is the commonly cited term in the scientific literature (Holling, 2001; Cinner et al., 2012d), but 'linked social-ecological systems' (Hughes et al., 2005), 'coupled human-environment systems' (Young et al., 2006), 'coupled human and natural systems' (Liu et al., 2007a) or 'social-environmental systems' (Diaz et al., 2011) are also used. The multiplicity of terms referring to the interplay of social and ecological systems reflects the different disciplinary fields and intellectual traditions within which the

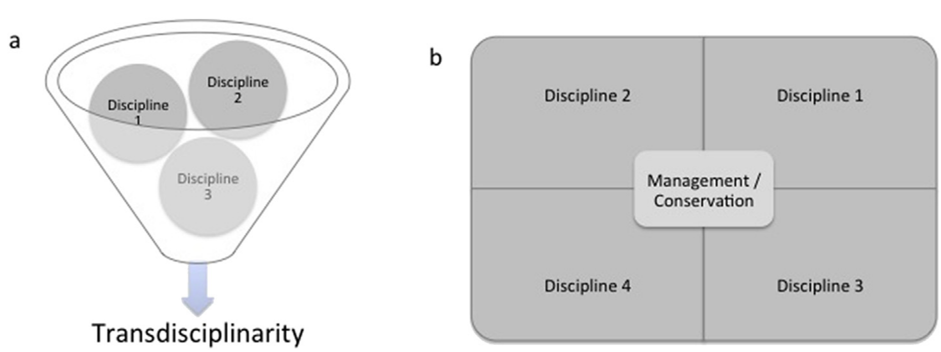

Fig. 1. a: Academic transdisciplinarity for the study of social-ecological systems. The academic way of creating a unified theory or concepts even before thinking about how this information may be useful or not for management. b: Interdisciplianrity or the reality of social-ecological conservation. Management objectives or conservation challenges require drawing out the most pertinent pieces of each discipline.

concept of SES has been developed. Indeed, several schools of thought, investigating notions and themes such as resilience, commons and complexity, political ecology, vulnerability, robustness, biodiversity and ecosystem services, have focused on social-ecological dynamics in the context of natural resource management creating several different approaches and terms. However, all these different terms can affect and obscure the relevance of the SES concept to applied conservation and management (Janssen et al., 2006). Today, some of this transdisciplinary thinking is housed within complexity science, which provides a new and useful paradigm to investigate linked social-ecological systems.

2.2. Connections between ecosystem-based management and social-ecological studies

Ecosystem-Based Management (EBM) is a relatively new approach in natural resource management, which aims for sustainable delivery of ecosystem services and benefits to human communities while simultaneously maintaining healthy, productive ecosystems. EBM is a practical response to theoretical research on social-ecological interactions in marine systems, taking a holistic approach which moves away from focusing management on single species and builds a complex management approach that considers cumulative impacts and interactions between ecosystem components as well as human resource users (McLeod et al., 2005). Successful implementation of EBM, however, requires deep knowledge of the feedbacks between social and ecological systems and the thresholds in these coupled systems that lead to shifts in ecosystem condition and social wellbeing (Leslie and McLeod, 2007). Therefore, EBM is a place-based approach rooted in understanding the linkages between people as resource users and the natural ecosystems communities depend. Inherently, the success of EBM hinges on insights from SES work that identifies connections, cumulative impacts, and multiple objectives in complex human-natural environments (Leslie and McLeod, 2007). Conceptually, EBM holds that natural resource management is about managing people's behavior in ecosystems, rather than the ecosystems themselves, and requires a holistic examination of how human activities affect all functions of the relevant ecosystem (Leslie and McLeod 2007), which in turn, is largely based on SES research in practical settings on different geographical scales. Such a shift in practical management challenges has also stemmed to a certain extent from SES insights and has led to EBM implementation policies in various regions, including the US West Coast, Australia, Canada, and the European Union (McLeod and Leslie, 2009).

2.3. Defining a complex systems approach to social-ecological systems

Social-ecological systems are complex adaptive systems sharing characteristic features of cross-scale linkages, emergent properties, non-linear dynamics and uncertainty (Gallopín et al., 2001; Gunderson and Holling, 2002; Buizer et al., 2011; Parrott and Meyer, 2012; Levin et al., 2012).

SES processes occur over a wide range of scales and induce **cross-scale linkages**. Applied SES science necessarily needs to cover broad spatial and temporal scales equally in order to tackle the full complexity of the SES under investigation (Gunderson and Holling, 2002). Complexity science stresses the hierarchical coupling of ecological and social systems across organizational, spatial and temporal scales. This paradigm highlights the nesting of local systems in larger ones (e.g. regional or global) and the cumulative effects of local processes on global processes (Bodin et al., 2006; Kininmonth et al., 2011). Likewise, complexity science emphasizes the local coupling of social and ecological systems at each scale, the embedding of smaller-scale processes in larger ones and the influence of larger-scale processes on smaller ones (Liu et al., 2007b). Gunderson and Holling (2002) summed up the concept of cross-scale interactions when stressing that "increasingly, local problems of the moment can have part of their cause located half a planet away and have causes whose source is from slow changes accumulated over centuries" (Gunderson and Holling, 2002).

One of the biggest challenges in social-ecological science is that SESs have unique **emergent properties**. Such properties do not belong to social or natural systems separately but emerge from the interactions across these linked systems (Liu et al., 2007b). The term emergence is used to describe unexpected or unpredictable spatial and/or temporal patterns of the structure and of the dynamics of a system, such as the resilience of an SES (Parrott, 2002). Emergent patterns may, in turn, have cross-scale feedbacks on different parts of the system. The observation of SES emergent patterns or properties is crucial to understand the dynamics of the system and has catalyzed scientific interests during the last decade (Folke, 2006). For example, Pollnac et al. (2010) used a meta-analytical approach to study SESs related to 127 marine reserves and showed that emergent patterns of social drivers modulated compliance behavior and thus ecological effectiveness of the reserves (Pollnac et al., 2010). As SESs are adaptive systems, emergence of new trajectories and dynamics are possible and likely when an SES is subjected to disturbances (Levin and Lubchenco, 2008), including, for example, in fisheries co-management settings (Ayers and Kittinger, 2014; Levine and Richmond, 2014). Thus, the response of a disturbed SES can be viewed as a unique and erratic trajectory for the system to regenerate, re-organize, or both from a disturbance (Plummer and Armitage, 2007).

An important characteristic of SESs involves **non-linear dynamics** that are difficult to predict. Thresholds, tipping points, and hysteresis all describe non-linear systems that evolve across multiple basins of attraction for dynamic systems subject to changing environmental pressures (Levin, 1998; Holling, 2001). Non-linearity generates interactions that can change as the system evolves (Folke, 2006). For example, Koch et al. (2009) demonstrated that the ecosystem service of coastal protection was non-linear and dynamic. They showed that there are many important factors, such as plant density and location, species, tidal regime, seasons, and latitude, that can also influence the patterns of non-linearity of this ecosystem services (Koch et al., 2009).

Finally, the cumulative effects of cross-scale, emergent properties are dynamic, non-linear interactions that create substantial and inherent **uncertainty** in socio-ecological systems. Uncertainty shapes SES trajectories (Fischer et al., 2009) and therefore the management of SESs is closely linked to the management of uncertainty, which conservation and resource management continue to struggle with, especially against the backdrop of climate change. While uncertainty is a key parameter emerging both from the cumulative complex interactions described above and from SES attributes, it remains difficult to incorporate into conservation and management (Wilson, 2006; Anderies et al., 2007; Polasky et al., 2011). Consequently, modeling SES dynamics requires tools and techniques to account for this inherent uncertainty (Olsson et al., 2008; Ostrom, 2009; Armitage et al., 2009).

2.4. Towards an empirical approach for the real world

2.4.1. Social-ecological monitoring

A key challenge of studying and managing socio-ecological systems has been a lack of standardized and rigorous data that link changes in ecological processes to responses in social dynamics and subsequent feedbacks between them. Monitoring dynamic and linked marine socio-ecological systems in the real world (e.g., coastal fisheries) is imperative for structured decision-making and adaptive management (Holling, 1978; Armitage et al., 2009), specifically in terms of human or environmental pressures (e.g., climate change, fishing effort) are mediated by management responses to affect social-ecological state and benefits. For example, Cinner et al. (2013) investigated the socio-ecological vulnerability of coral reef fisheries in Kenya to climate change using indicators of climate exposure, biological resistance and recovery, social sensitivity to change and social adaptive capacity to recover and reorganize. Importantly, this approach was the first to quantify the ecological vulnerability of coral reefs to climate change along with social vulnerability of fishing communities to changes in the ecological system, such as the dependence on fishing and the ability to learn from and adapt to climate shocks. By identifying vulnerable coastal communities in a changing climate, this approach assessed socio-economic and governance actions to reduce future vulnerability. This is one example of a rigorous, empirical monitoring data that strategically combine surveys of ecological and social systems (i.e., transdisciplinary studies) to inform conservation and management practices.

2.4.2. Perspectives from modeling

Modeling human behavior is key for the development of policy-relevant scenarios based on field studies facilitating the design of adaptive management initiatives (Österblom et al., 2013). More place-based SES studies are needed to build scenarios able to appropriately inform decision-makers and managers. Place-based SES studies require additional data collection methods and a more comprehensive suite of key indicators (Biggs et al., 2012b). In tropical environments, fine-tuned modeling and planning frameworks were used to deliver management with adaptation schemes (Cinner et al., 2009b, 2013; Cinner, 2011; Kittinger et al., 2012). Such creative and advanced methods need to be incorporated into more formal modeling procedures (Clark, 2004; Uusitalo, 2007; Aguilera et al., 2011), such as Qualitative Comparison Analysis (Bodin and Österblom, 2013), Structural Equation Modelling (Grace, 2006) or Bayesian Belief Networks (van Putten et al., 2013; Kininmonth et al., 2014).

2.4.3. The need for social data

Resource managers and conservationists are often trained to base their planning initiatives on biological, ecological, and physical data and consequently do not use social data in ocean planning (Le Cornu et al., 2014). However, high quality social data and the inclusion of people in decision-making in a top-down/bottom-up hybrid management or conservation planning process usually creates more robust and long-lasting governance structures (Koehn et al., 2013; Kittinger et al., 2014). The lack of social data relating to human-nature interactions in a particular context is now seen as an omission which can often erode the efficacy of any resource management or conservation action. For example, many studies have shown that when social data are not incorporated into planning decisions, the initiatives often have limited success and sometimes unintended outcomes (Christie, 2004; Cinner et al., 2009a; Fulton et al., 2011; Kittinger et al., 2013). This has led to the development of social indicators of food security, poverty alleviation, human well-being in the context of marine resource management, and conservation planning (Mills et al., 2013b; Ban et al., 2013; Milner-Gulland et al., 2014; Stephanson and Mascia, 2014). Kittinger et al. (2014) proposed a useful step-by-step guide for the incorporation of social data into effective and efficient ocean and coastal science, modeling and ultimately, planning and resource management. However, these efforts require a concerted effort by scientists to conceive, fund, and conduct joint SES studies to assess practical resource management and conservation tradeoffs (Ban and Klein, 2009; Koehn et al., 2013; Le Cornu et al., 2014; Kittinger et al., 2014). While theoretical frameworks of integrated social and ecological processes are available to inform conservation planning (Ban et al., 2013; Le Cornu et al., 2014), there are fewer case studies based on empirical datasets which include social data that may arguably hold more practically usable information for adaptive management.

3. Case studies: the importance of context and culture

The extent to which people in different regions of the world view themselves as a part of natural ecosystems has fundamental implications about how people in such different regions approach conservation, resource management and sustainability. Our deeply culturally ingrained legacies of people-nature relationships guide the level to which people conserve nature, and perceive connections between nature and their own wellbeing. Social-ecological research can unveil these connections in important ways, not only for the scholarly effort of understanding behavior, but also for finding extremely practical implications for effective resource management and conservation (Milner-Gulland et al., 2014).

One of the premises of SES modeling is that ecosystems and society are inextricably linked and that any delineation between the two is arbitrary (Berkes et al., 2003). Local communities' perceptions of natural resources and resource management regimes, as well as the perceptions of the underlying cultural, historical, nutritional, and appropriative ties of the community with the natural resources is recognized as critical management-relevant and conservation-planning information in both terrestrial and marine systems (Cinner and David, 2011; Kittinger et al., 2012; Bennett and Dearden, 2014; Stephanson and Mascia, 2014). Therefore, to have the highest likelihood of success for management and conservation decisions, social-ecological studies need to focus on the most appropriate place-based design and choice of relevant social and biophysical indicators (Bauer, 2003; Cinner and Pollnac, 2004; Koehn et al., 2013; Le Cornu et al., 2014; Kittinger et al., 2014).

Highlighting tradeoffs, synergies, costs and benefits between social and ecological outcomes is also critical for SES research (Ban and Klein, 2009) as case studies strive to identify enabling factors for a triple bottom-line of positive socio-economic, cultural, and environmental outcomes (Halpern et al., 2013). Tremendous insights have been gained from the development of generalizable frameworks for social-ecological relationships (Ostrom, 2007, 2009), as well as frameworks for particular types of ecosystems (e.g., coral reefs: Cinner, 2014; Kittinger et al., 2012). Cultural diversity is a significant factor modulating institutions of planning, both conservation planning as well as development planning. There is a strong role to be played by SES research to elucidate cultural aspects in a given natural resource management context that will facilitate the planning process (Poe et al., 2014). Here, we highlight the role of local context and culture with three case studies from the Pacific Ocean and one case study from the Baltic Sea.

3.1. The Polynesian context

Here, we discuss the cultural contexts of the Hawaiian Islands, French Polynesia, and American Samoa as examples of marine SESs that merit a thorough consideration of cultural, political, and historic drivers of natural resource management (cf. Fig. 1). Hawai'i, American Samoa, and French Polynesia all exist in a dichotomy, where Pacific island groups have Polynesian history and heritage but governed by typically western (North American and European) governance structures and management regimes (Ayers and Kittinger, 2014; Levine and Richmond, 2014; Gaspar and Bambridge, 2008). In all three locations, centralized top-down fisheries management approaches are implemented by the non-native governance agencies on many largely isolated rural areas. However, all these Pacific islands also have strong centuries-old cultural heritage of forms of resource stewardship, integrated mountain-to-sea (i.e., ridge-to-reef) management, and sustainable use of fisheries (Bambridge, 2012). Thus effective conservation and management that matters requires considering traditional cultural heritage and marine tenure systems within the contemporary structures of governance.

3.1.1. Hawai'i, USA

In Hawai'i, traditional management systems, such as the watershed-based tenure system known as *ahupua'a* (Kittinger et al., 2011; Levine and Richmond, 2014), were practiced successfully and sustainably for centuries, but have arguably not been well-integrated with the modern western management systems, which often seem to result in both erosion of traditional sustainable management as well as failure to meet management goals (Ayers and Kittinger, 2014). Often, the western management planning process does not appear conducive to multicultural inputs, with the potential to marginalize traditional ecological knowledge (TEK) of indigenous people from the rule-making process as well as the governance structures (Levine and Richmond, 2014). However, traditional marine resource management institutions in Hawai'i are increasingly seen by state government agencies as a system to learn from on the pathway to successfully leveraging Polynesian cultural heritage and localization of autonomy in the management of marine resources for abundance and sustained benefits to people (Ayers and Kittinger, 2014).

In 1994, Hawaii passed legislation for the establishment Community-Based Subsistence Fishery Areas (CBSFAs), which created a process for localizing rule-making processes and revitalizing community-based management (Levine and Richmond, 2014). While the CBSFA legislation was heralded as a step forward towards formalizing the process of co-management, the implementation of the new institution has not been as efficient as expected due to challenges with resource depletion, conflict (and lack of conflict resolution mechanisms), self-organization, consensus-building, and collective action (Ayers and Kittinger, 2014). As community collaborative management, or co-management, for small-scale fisheries continues to evolve and demonstrate success around the world (Berkes, 2010; Cinner et al., 2012a, 2012b, 2012c, 2012d; Gutiérrez et al., 2011), it becomes clear in Hawai'i that such local, place-based, collaborative management structures generate greater social and cultural legitimacy and ultimately greater management success when implemented within the local cultural context (Ayers and Kittinger, 2014).

3.1.2. Moorea, French Polynesia

Moorea, an island under French government jurisdiction in the South Pacific, is characterized by diverse resource users due to the island's proximity to an urban center and fish-market, Papeete, in Tahiti. Income from coral reef-associated recreational activities represents the main economic resource of the island. Resource users include Moorea residents, Polynesian (Tahitian) and international tourists who engage in scuba-diving, snorkeling and boating. Fishing activities are mostly driven by subsistence fishing and hold an important cultural role in the Polynesian society (e.g. enjoyment, identity, prestige and a life style) (Cinner, 2014) (cf. Figs. 2 and 3).

In order to manage recreational and fishing uses of the Moorea lagoon resources, a management plan, called PGEM ("Plan de Gestion de l'Espace Maritime"), was established in 2004, after 10 years of consultation with all users of the lagoon. The PGEM regulates the entire Moorea lagoon and the Moorea outer slope (down to 70 m depth). The management plan is a marine spatial planning tool that

Fig. 2. A) Convict tangs (*Acanthurus triostegus*; Hawaiian name: manini) drying on lava rock on Hawaii Island, Hawaii ((c) Conservation International, S. Kehaunani Springer); B) Hawaiian fisherman with net ((c) Conservation International, S. Kehaunani Springer); C) Variety of reef fish species caught in Moorea ((c) Pierre Leenhardt); D) Tourism in the no-take reserve in Moorea ((c) Thomas Vignaud).

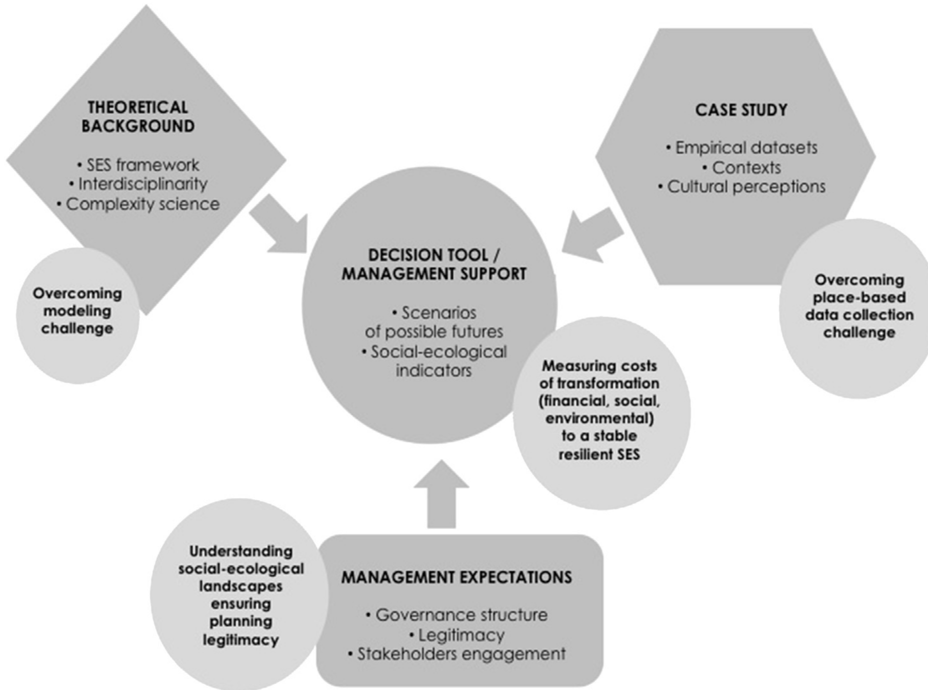

Fig. 3. Ingredients for making marine social-ecological science matter for conservation and management decisions: Theoretical backgrounds, real world case studies and consideration of management expectations contribute to decision tools and management support through scenario planning and stakeholder engagement.

includes a network of eight permanent marine protected areas (MPAs) implemented with the objectives of biodiversity conservation and fisheries management (i.e. 5 no-take zones and 3 fishing gear limitation zones). The MPAs are monitored annually since their implementation, but to date the monitoring program has focused only on the assessment of ecological benefits. After ten years of protection the ecological benefits of the network of MPAs were limited (Lison de Loma et al., 2008) (Thiault et al., pers com). Drivers of such a pattern may stem from natural processes: coral bleaching, a crown-of-thorns starfish (COTS) outbreaks (2006–2009), and a hurricane (2011) may have hampered the provision of benefits from the MPAs. However, social feedbacks are undoubtedly important, as compliance is not high in those MPAs (MacNeil et al., 2015).

From a social perspective, the PGEM has always been strongly criticized and still suffers from a process legitimacy issue. This social disappointment might stem from two cultural drivers: (1) many specific cultural ecosystem services important to the people of Moorea throughout their history are not directly the concern of the PGEM. Moreover, recreational activities and tourism did not have a dominant place in the system of Moorea fifty years ago, and (2) the Polynesian culture is largely reef oriented in terms of knowledge, traditions and resources. Tahitian and related languages in the different archipelagos of the Territory have more vernacular names for coral reef habitats and fauna and flora species than any other language in the world (Salvat and Pailhe, 2002). Moorea as well as all Polynesian islands represent a region where culture and nature are strongly connected and there is a deep cultural heritage of environmental stewardship. Moreover the Polynesian people have always viewed a continuous relationship between the lagoon and the land considering their natural resources “from the top of the mountain to the reef crest” at the same level (Bambridge, 2012).

3.1.3. American Samoa, USA

In 2000, the American Samoa Department of Marine and Wildlife Resources (DMWR) led a process to institutionalize co-management in the US territory through the development of a Community-Based Fisheries Management Program (CFMP). Although the intent on developing co-management agreements was similar in Hawai'i and American Samoa, the social, cultural, historic, and political context were different, and therefore had the potential for different outcomes (Levine and Richmond, 2014). American Samoa, lying more than 3700 km south of Hawai'i, is generally characterized by a less diverse and less affluent population than Hawai'i. In contrast to Hawai'i, American Samoa has retained a decentralized nature of marine resource management, as village councils maintain and uphold traditional land and marine tenure practices (Levine and Richmond, 2014).

The American Samoa government aimed to ensure process legitimacy in its development of the CFMP and was focused on village cooperation and involvement in the CFMP formulation (Levine and Richmond, 2014). The CFMP was designed as a voluntary scheme of co-management, wherein a village council, which had limited ability but strong interest in managing and enforcing marine resource use on a local level, would develop a collaborative management and enforcement plan best suited to the sustainability of the village's particular marine resource dynamics and local community needs. Twelve villages have successfully developed CFMPs with the American Samoa government; whereas, in Hawai'i, only one community has its co-management rules package accepted by the state government, even though the legal framework for co-management was available earlier in Hawai'i than in American Samoa.

3.2. Ingredients for co-management success in the Pacific

Research on place-based SESs has revealed that in Hawai'i, Polynesia and American Samoa, as well as in other parts of the world, there are exogenous and endogenous factors which control the success or lack of success in development of co-management agreements on a local level which target social-ecological resilience (Gutiérrez et al., 2011; Levine and Richmond, 2014; Ayers and Kittinger, 2014). Exogenous (or external) factors relate to the top-down imposition of a foreign natural resource management system on a culture, which has traditionally held a different human-nature connection begetting different marine resource use and management pattern. In this context, western-style bureaucratic management styles implemented in Moorea, with separate terrestrial and marine management have yielded 20 years of mismatches between state governance priorities and processes with traditional Polynesian environmental management styles. Such mismatches coupled with intensified human impacts on Pacific island terrestrial and marine environments due to increase in population density and proximity to urban centers have resulted in environmental decline (Cinner et al., 2012a, 2012b, 2012c, 2012d).

Some of the endogenous (or internal) factors that challenge the formulation of management initiatives that sustain social-ecological resilience in marine systems stem from the level of cultural and ethnic diversity as well as present or absent community structures. Studies have shown that group homogeneity or a singular cultural identity with little diversity of values and incentives can be a key factor for collective action in common-pool resource management (Baland and Platteau, 1996; Jentoft, 2000). Levine and Richmond (2014) propose that while traditional marine tenure systems, community structures, traditional social hierarchies and cultural identities are strong and remain intact in most locations in American Samoa, the same characteristics have been significantly disrupted in Hawai'i, where currently Hawaiians and part Hawaiians represent a minority and where local marine tenure systems and community leadership can gather momentum only in locations where traditions of subsistence fishing are still practiced. It is likely that the lack of village-level governance systems in Hawaii compared to American Samoa also has presented a barrier to developing community capacity for management and the implementation of the CBSFA legislation (Levine and Richmond, 2014).

In all three Polynesian island contexts presented here, the cultural heritage of stewardship holds much promise for initiatives in collaborative management with state government. However, if local contexts such as the political landscape, power balances, population density, cultural diversity, the level of community cohesion, and the leadership aspects are not fully considered, western-based planning processes may not be successfully integrated with community-level capacity for consensus-building and effective plans for management and adaptation to environmental change (Henly-Shepard et al., 2015). More SES studies are needed, specifically, community-based assessments and gap analyses for transformation, to highlight level of risk or low resilience.

3.3. The European context: the case of the Baltic Sea

The Baltic Sea is a semi-enclosed brackish sea that contains a depauperate set of marine and fresh water species (Österblom et al., 2007). The salinity gradient is highly influential on the species ranges and combined with seasonal ice conditions, wind patterns, fresh water inflows and variable Atlantic water inflows influences the biodiversity patterns and dynamics. Additionally over the past 100 years the impact of anthropogenic pressures such as toxic inputs, nutrient input, hunting and fishing have influenced the species distributions (Österblom et al., 2007; Lowe et al., 2014). The effect of a changing climate is also attributed to shifts in species abundances (Möllmann et al., 2009). The combined effects have resulted in a complex disturbance of the marine food web (Niiranen et al., 2013).

Managing the human activities on the Baltic Sea immerged as a necessity when clear indications of ecological and environmental change occurred (MacKenzie et al., 2011). Fisheries in particular were nationally regulated despite the Baltic Sea being shared between 9 countries. Regime shifts have been observed in multiple occasions with large increases in Cod (*Gadus morhua*) and herring (*Clupea harengus*) (Österblom et al., 2007). Seal numbers were reduced by 95%, mainly due to hunting, during the twentieth century with subsequent reduction in top down control for cod abundances. Eutrophication due to nutrient inputs has altered the bottom oxygen concentrations and has been blamed for the reduced spawning capacity of cod (Lindegren et al., 2014). Increased fishing pressure as a result of the cod high abundance combined with changes in benthic oxygen and salinity conditions led to a collapse of the cod populations in the late 1980's (Koster et al., 2005). Social changes have followed these ecological shifts with a marked reduction (93% in Sweden; Brookfield et al., 2005) of small-scale fishing operations.

In response to these changes and with an international convention on protection of the Baltic Sea (HELCOM) vision of restoring the Baltic Sea to a previously productive state there have been a number of initiatives. Eutrophication reduction is proving difficult due to sustained loads of nutrients despite the implementation of national and international policies. HELCOM for example has had in place the Baltic Sea Action Plan since 1970. More recently the European Union delivered a 2008 Marine Strategy Framework Directive but the problem still remains due to decision, implementation and ecosystem delays (Varjopuro et al., 2014). These delays can be measured in decades and it is proposed that monitoring activities combined with reflexive, participatory analysis of ecosystem dynamics can help understand the deferrals (Varjopuro et al., 2014). Managing the fisheries activities is not just about sustainable catch limits but involves the holistic appreciation of social and environmental factors (Lade et al., 2013; Niiranen et al., 2013). Top-down limits on fish catches imposed in recent years have failed to be realized as the cod abundances and size remained commercially unviable. The original HELCOM 1974 convention did not include territorial waters and limited the regulation of land based pollution. This was rectified in 1992 with a more comprehensive convention containing all the Baltic Sea countries and introducing concepts such as ecosystems (Blenckner et al., 2015). Two major challenges are facing the Baltic Sea management; Climate change and intensified energy installations. With a catchment of 1,720,000 km^2 containing 85 million of people the impact on ecosystem services is significant. Critical to the effectiveness of the management is the shift from isolated pressure – response actions to integrated state-based management that recognizes the complex interaction of people and environment (Österblom et al., 2013).

4. Towards a marine social-ecological conservation

4.1. Integration of social components into social-ecological system management

- Frameworks for MPA management effectiveness

Typically, marine resource management attempts to regulate fishing effort through the establishment of no-take marine protected areas (MPAs), gear restrictions or size limits on take. However, such restrictions often (especially in small-scale fisheries in the developing world) are not successful because they attempt to treat symptoms rather than root social context of resource exploitation, such as poverty traps, weak governance, lack of social welfare and economic safety nets, lack of alternative livelihoods (Cinner et al., 2009a; Kittinger et al., 2013). Particularly relating to MPAs, there is an emerging body of evidence to evaluate the social impacts of MPAs and identify socio-economic factors of MPA success or failure and elucidate trade-offs between social and ecological goals in integrated management (Ehler, 2003; Pomeroy et al., 2005;

Himes, 2007; Cinner et al., 2009b; Pajaro et al., 2010; Gurney et al., 2014). For example, Gurney et al. (2014) used a framework for assessing the impact of MPA management on poverty. Several components of poverty domains such as livelihood diversity, resource dependence, conflicts, well-being, financial capital, human capital, natural capital, resource access, influence in community and governance mechanism were used to help to examine the relationships between natural resource management and poverty. Clearly, social contexts are a fundamental goal of social-ecological systems management (Fig. 3). Moreover, the effect of conservation actions on people is likely to vary with project and context (Cinner et al., 2012c). Only through the construction of a portfolio of case studies can we obtain an understanding of the heterogeneous impacts of conservation, and provide insights to build new projects to better achieve social goals (Gurney et al., 2014).

- Towards the management of social-ecological resilience

The emerging strong interest in resilience across SESs also cautions that social-ecological studies need to be carefully designed to inform management for resilience. Insofar as SES research can provide insight into the transition and transformation towards sustainable and equitable marine resource use, as well as resilient ecosystems and social systems, some of the highest value in SES research lies in evaluating governance regimes, resource users' incentives (Ostrom, 2007; Smith and Stirling, 2010) and the level of dependence of social systems on maintained ecological benefits (Mills et al., 2013a; Gurney et al., 2014). SES studies have continued to focus on what the most appropriate social indicators in a given setting that should be monitored to provide useful information on local conditions that confer social-ecological resilience or vulnerability, as well as information that would directly facilitate improvements in management processes and outcomes (Biggs et al., 2012b; Cinner et al., 2013). This focus has guided research on SESs with understanding how the inextricably connected systems function can move the system to a more stable and resilient state (Turner et al., 2003a, 2003b, Ostrom, 2007, 2009).

A review on social indicators that monitor SES resilience and can inform management reveals several focal domains. Indicators key for insights into social resilience and effective management structures appears to focus on (1) empowerment which includes the capacity to organize and participate in decision-making; (2) ability to adapt, or retain flexibility, which can have various measures, including livelihood diversity in a household, household size, ability to learn, level of education, etc.; and (3) capital, including financial, material, and social capital (Cinner et al., 2009b; Mills et al., 2013b; Gurney et al., 2014; Stephanson and Mascia, 2014). Within this general realm of indicators, place-based SES research needs to be carefully attentive to local cultural values, social dynamics, and political landscapes in order to craft the most appropriate indicators.

- Insights from co-management

Furthermore, social-ecological studies on community-based marine collaborative management (co-management) initiatives reveal some of the keys to success in place-based management, with the academic effort of SES research directly serving to inform management improvements that take advantage of enabling conditions defined by integrated social-ecological indicators and historical studies of cultural decision contexts (Kittinger et al., 2013). Co-management can be differentiated in two main processes: (1) collaborative management involving the practical and technical aspects of management activities, and (2) shared governance, that is sharing the governance institutions and decision-making processes between a stakeholder group and a state agency (Berkes, 2010; Cinner et al., 2012a). The body of empirical studies on the level of participation and decision-making in the development of co-management institutions is growing (Berkes, 2010; Cinner et al., 2012a; Ayers and Kittinger, 2014). In analyzing more than 130 community-based co-management arrangements, Gutierrez et al. (2011) concluded that strong leadership is one of the most important enabling factors for successful and lasting co-management setting with benefits for both nature and people.

Several key factors that facilitate the localization of successful management, beyond the context of co-management frameworks, have emerged centering on the significance of the government agency leading the implementation of culturally legitimate processes congruent with local cultural values (Berkes, 2010; Fox et al., 2013; Kittinger et al., 2013). The agency leading the process has to ensure process legitimacy, equity, and transparency within the planning and implementation effort and carefully account for major process drivers, social incentives for engagement, community cohesion, costs, and timelines (Basurto et al., 2012; Fox et al., 2013; Gleason et al., 2013; Ayers and Kittinger, 2014). The enabling conditions for successfully transforming to socially sustainable management systems include: (1) conflict resolution mechanisms, (2) trust, (3) cohesion, high level of community organization, and shared development of problem and pathway, (4) clear definition of roles, responsibilities, and interests (Kauneckis et al., 2005).

To make SES research most useful in adding practical value to conservation planning, marine resource management planning processes and implementation, and the integration of resilience thinking into adaptation strategies (Levin and Lubchenco, 2008), more research is needed on (1) understanding social-ecological landscapes and seascapes and patterns that would ensure planning process legitimacy, (2) costs of transformation (financial, social, environmental) to a stable resilient social-ecological system, (3) overcoming place-based data collection challenges as well as modeling challenges (Fig. 3).

4.2. How to align social-ecological research with policy needs?

Although a set of "good practices" about what constitutes a good SES study are emerging, there is still a disconnect between generating SES scientific studies and providing decision-relevant information to policymakers. Classical single variable/hypothesis studies rooted in one or two disciplines are still most common, leading to incremental growth in knowledge about the natural or social system, but rarely both. Policymakers, meanwhile, especially those whose decisions are not motivated by environmental conservation, want to know who will be affected by changes in marine resource availability, where these effects will emerge, and when they will occur. There is an inherent mismatch in the detail and focus of the information provided by scientists and sought by decision makers.

Several obstacles stand in the way of developing and implementing fully fledged SES studies as described here. At present, funds and coordination to conduct SES studies at the levels of detail and practice outlined in this paper are not often available, simply because SES studies are generally larger and longer term than classical studies examining a few variables at a time (Langer, 2012; Rodrigo et al., 2013). SES studies also require bringing together scientists trained in many different traditions, but many scientists often simply do not know specialists from other disciplines with whom to collaborate. Once networks of multidisciplinary scientists are convened, communication must be ensured (e.g. by establishing a common "glossary") to overcome divergent vocabularies (Bracken

Table 1
Challenges, insights and perspectives of social-ecological science for conservation.

	Frame	Needs
Challenges	Transdisciplinarity	Integrative approach
	Complex system theory	To account for cross-scales linkages, non linear dynamics, emergent phenomena, uncertainty
	Social-ecological monitoring	To monitor standardized and rigorous data that link changes in ecological processes to responses in social dynamics for adaptive management
	Modeling	To have social data relating to the human-nature interactions that can be incorporated into models for decision help
Insights	Cultural	To account for deeply culturally ingrained legacies of people—nature relationships that guide the level to which people conserve nature, and perceive connections between nature and their own wellbeing
	Co-management	To account for level of cultural and ethnic diversity as well as present or absent community structures, cultural heritage of stewardship, political landscape, power balances, population density, cultural diversity, the level of community cohesion, and the leadership aspects are not fully considered
Perspectives	Management effectiveness	Integration of MPA social effectiveness indicators such as livelihood diversity, resource dependence, conflicts, well-being, financial capital, human capital, natural capital, resource access, influence in community and governance mechanism Integration of social Indicators to monitor SES resilience such as: (1) empowerment which includes the capacity to organize and participate in decision-making; (2) ability to adapt, or retain flexibility, which can have various measures, including livelihood diversity in a household, household size, ability to learn, level of education, etc.; and (3) capital, including financial, material, and social capital Socially sustainable management systems that include: (1) conflict resolution mechanisms, (2) trust, (3) cohesion, high level of community organization, and shared development of problem and pathway, (4) clear definition of roles, responsibilities, and interests. To align social-ecological science with marine resource management challenges through an *Ecosystem-Based Management* approach
	Social-ecological science	(1) Understanding social-ecological landscapes and seascapes and patterns that would ensure planning process legitimacy, (2) costs of transformation (financial, social, environmental) to a stable resilient social-ecological system, (3) overcoming place-based data collection challenges as well as modeling challenges.

and Oughton, 2006), and a shared theoretical framework must be established that all participants can work within (Binder et al., 2013). Products that report on the outcomes (e.g., peer-reviewed journal articles, reports, web sites, public presentations, etc.) must be planned that will be equally rewarding to all contributors, despite their different research interests, approaches, and ways in which contributors are evaluated (Table 1).

Providing decision-relevant information to policy-makers about an SES requires answering the who, what, when, where, and why-style questions mentioned above and clearly connecting this information to specific policy-makers' primary interests, such as voting constituents, resources of interest, laws to uphold, etc. Ideally, SES studies should be structured at the outset to provide insight on these questions (Ash et al., 2010). The integration of social indicators into SES management should directly facilitate improvements in management by providing decision-relevant information to policymakers about an SES (Fig. 1). When this is not the case, knowledge gained must be synthesized or extrapolated to answer policymakers' questions. Although this can be done in some instances, in others this approach risks increasing uncertainty or going beyond the limits of the study.

5. Conclusion

There have been repeated calls for a transdisciplinary approach to complex linked socio-ecological systems (SESs) that incorporates resilience, complexity science, emergent properties, non-linear dynamics and uncertainty. To achieve this vision, we need to embrace diverse research methodologies that incorporate ecology, sociology, anthropology, political science, economics and other disciplines that are anchored in empirical data. Here, we synthesize conceptual frameworks, applied modeling approaches, as well as case studies to highlight complex SES dynamics that inform environmental policy, conservation and management (Table 1). While a number of modeling approaches have been developed, robust social-ecological monitoring and empirical social datasets remain scarce, limiting our ability to fully consider the complex processes, functions and dynamics of SESs. Furthermore, the local context of political landscapes, power balances, population density, cultural diversity and community cohesion are crucial information for adapting conceptual frameworks towards case specific approaches (Kittinger et al., 2013). Finally, our case studies from the Pacific and the Baltic sea highlight that cultural perceptions of SESs need to be better integrated into management schemes in order to avoid mismatches between state governance priorities and traditional environmental management styles.

Acknowledgment

Preparation of this paper was carried out with the financial support of the Project INTHENSE funded by the Fondation de France and by the Programme Doctoral International: Modélisation des Systèmes Complexes (PDIMSC). We are grateful to the organisations that supported participation of the co-authors in the 3rd International Marine Conservation Congress in August 2014 in Glasgow, Scotland. We also thank Olivia Langmead and Ness Smith for their crucial inputs during the preliminary discussion of this paper.

References

Aguilera, P.A., Fernández, A., Fernández, R., Rumí, R., Salmerón, A., 2011. Bayesian networks in environmental modelling. Environ. Model. Softw. 26 (12), 1376–1388.
Anderies, J.M., Rodriguez, A.A., Janssen, M.A., Cifdaloz, O., 2007. Panaceas, uncertainty, and the robust control framework in sustainability science. Proc. Natl. Acad. Sci. USA 104 (39), 15194–15199.
Armitage, D.R., Plummer, R., Berkes, F., Arthur, R.I., Charles, A.T., Davidson-Hunt, I.J., Diduck, A.P., Doubleday, N.C., Johnson, D.S., Marschke, M., McConney, P., Pinkerton, E.W., Wollenberg, E.K., 2009. Adaptive co-management for social—ecological complexity. Front. Ecol. Environ. 7 (2), 95–102.
Ash, N., Blanco, H., Brown, C., Garcia, K., Tomich, T., Vira, B., 2010. Ecosystems and

Human Well-being: a Manual for Assessment Practitioners. Island Press.
Ayers, A.L., Kittinger, J.N., 2014. Emergence of co-management governance for Hawai'i coral reef fisheries. Glob. Environ. Change 28, 251–262.
Baland, J., Platteau, J., 1996. Halting Degradation of Natural Resources.
Bambridge, T., 2012. Savoirs traditionnels et biodiversité en Polynésie française. Cult. Recherche 2012.
Ban, N.C., Klein, C.J., 2009. Spatial socioeconomic data as a cost in systematic marine conservation planning. Conserv. Lett. 2 (5), 206–215.
Ban, N.C., Mills, M., Tam, J., Hicks, C.C., Klain, S., Stoeckl, N., Bottrill, M.C., Levine, J., Pressey, R.L., Satterfield, T., Chan, K.M., 2013. A social–ecological approach to conservation planning: embedding social considerations. Front. Ecol. Environ. 11 (4), 194–202.
Basurto, X., Cinti, A., Bourillón, L., Rojo, M., Torre, J., Weaver, A.H., 2012. The emergence of access controls in small-scale fishing commons: a comparative analysis of individual licenses and common property-rights in two Mexican communities. Hum. Ecol. 40 (4), 597–609.
Bauer, H., 2003. Local perceptions of Waza National Park, northern Cameroon. Environ. Conserv. 30 (2), 175–181.
Bennett, N.J., Dearden, P., 2014. Why local people do not support conservation: community perceptions of marine protected area livelihood impacts, governance and management in Thailand. Mar. Policy 44, 107–116.
Berkes, F., 2010. Devolution of environment and resources governance: trends and future. Environ. Conserv. 37 (04), 489–500.
Berkes, F., Colding, J., Folke, C., 2003. Navigating Social-ecological Systems: Building Resilience for Complexity and Change. Cambridge University Press, Cambridge, UK.
Bettencourt, L.M.A., Kaur, J., 2011. Evolution and structure of sustainability science. Proc. Natl. Acad. Sci. USA 108 (49).
Biggs, R., Schlüter, M., Biggs, D., Bohensky, E.L., BurnSilver, S., Cundill, G., Dakos, V., Daw, T.M., Evans, L.S., Kotschy, K., Leitch, A.M., Meek, C., Quinlan, A., Raudsepp-Hearne, C., Robards, M.D., Schoon, M.L., Schultz, L., West, P.C., 2012a. Toward principles for enhancing the resilience of ecosystem services. Annu. Rev. Environ. Resour. 37 (1), 421–448.
Biggs, R., Schlüter, M., Biggs, D., Bohensky, E.L., BurnSilver, S., Cundill, G., Dakos, V., Daw, T.M., Evans, L.S., Kotschy, K., Leitch, A.M., Meek, C., Quinlan, A., Raudsepp-Hearne, C., Robards, M.D., Schoon, M.L., Schultz, L., West, P.C., 2012b. Toward principles for enhancing the resilience of ecosystem services. Annu. Rev. Environ. Resour. 37 (1), 421–448.
Blenckner, T., Kannen, A., Barausse, A., Fischer, C., Heymans, J.J., Luisetti, T., 2015. Past and Future Challenges in Managing European Seas, vol. 20(1).
Bodin, Ö., Crona, B., Ernstson, H., 2006. Social networks in natural resource management: what is there to learn from a structural perspective? Ecol. Soc. 11 (2).
Bodin, Ö., Österblom, H., 2013. International fisheries regime effectiveness — activities and resources of key actors in the Southern Ocean. Glob. Environ. Change 23 (5), 948–956.
Buizer, M., Arts, B., Kok, K., 2011. Governance, scale and the environment: the importance of recognizing knowledge claims in transdisciplinary arenas. Ecol. Soc. 16 (1), 21.
Carpenter, S.R., Mooney, H.A., Agard, J., Capistrano, D., Defries, R.S., Díaz, S., Dietz, T., Duraiappah, A.K., Oteng-Yeboah, A., Pereira, H.M., Perrings, C., Reid, W.V., Sarukhan, J., Scholes, R.J., Whyte, A., 2009. Science for managing ecosystem services: beyond the Millennium Ecosystem Assessment. Proc. Natl. Acad. Sci. USA 106 (5), 1305–1312.
Carson, E., Feng, D.D., Pons, M.-N., Soncini-Sessa, R., van Straten, G., 2006. Dealing with bio- and ecological complexity: challenges and opportunities. Annu. Rev. Control 30 (1), 91–101.
Chapin, F.S., Carpenter, S.R., Kofinas, G.P., Folke, C., Abel, N., Clark, W.C., Olsson, P., Smith, D.M.S., Walker, B., Young, O.R., Berkes, F., Biggs, R., Grove, J.M., Naylor, R.L., Pinkerton, E., Steffen, W., Swanson, F.J., 2010. Ecosystem stewardship: sustainability strategies for a rapidly changing planet. Trends Ecol. Evol. 25 (4), 241–249.
Christie, P., 2004. Marine protected areas as biological successes and social failures in Southeast Asia. Am. Fish. Soc. Symp. 155–164.
Christie, P., 2011. Creating space for interdisciplinary marine and coastal research: five dilemmas and suggested resolutions. Environ. Conserv. 38 (02), 172–186.
Cinner, J.E., 2011. Social-ecological traps in reef fisheries. Glob. Environ. Change 21 (3), 835–839.
Cinner, J.E., 2014. Coral reef livelihoods. Curr. Opin. Environ. Sustain. 65–71.
Cinner, J.E., David, G., 2011. The human dimensions of coastal and Marine ecosystems in the western Indian ocean. Coast. Manag. 39 (4), 351–357.
Cinner, J.E., Fuentes, M., Randriamahazo, H., 2009a. Exploring social resilience in Madagascar's Marine protected areas. Ecol. Soc. 14 (1), 41.
Cinner, J.E., McClanahan, T.R., Daw, T.M., Graham, N.A.J., Maina, J., Wilson, S.K., Hughes, T.P., 2009b. Linking social and ecological systems to sustain coral reef fisheries. Curr. Biol. 19 (3), 206–212.
Cinner, J.E., Daw, T.M., McClanahan, T.R., Muthiga, N., Abunge, C., Hamed, S., Mwaka, B., Rabearisoa, A., Wamukota, A., Fisher, E., Jiddawi, N., 2012a. Transitions toward co-management: the process of marine resource management devolution in three east African countries. Glob. Environ. Change 22 (3), 651–658.
Cinner, J.E., Graham, N.J., Huchery, C., Macneil, M.A., 2012b. Global effects of local human population density and distance to markets on the condition of coral reef fisheries. Conserv. Biol. J. Soc. Conserv. Biol. 27 (3), 453–458.
Cinner, J.E., McClanahan, T.R., Graham, N.A.J., Daw, T.M., Maina, J., Stead, S.M., Wamukota, A., Brown, K., Bodin, Ö., 2012c. Vulnerability of coastal communities to key impacts of climate change on coral reef fisheries. Glob. Environ. Change 22 (1), 12–20.
Cinner, J.E., McClanahan, T.R., MacNeil, M.A., Graham, N.A.J., Daw, T.M., Mukminin, A., Feary, D.A., Rabearisoa, A.L., Wamukota, A., Jiddawi, N., Campbell, S.J., Baird, A.H., Januchowski-Hartley, F.A., Hamed, S., Lahari, R., Morove, T., Kuange, J., 2012d. Comanagement of coral reef social-ecological systems. Proc. Natl. Acad. Sci. 1–4.
Cinner, J.E., Huchery, C., Darling, E.S., Humphries, A.T., Graham, N.A.J., Hicks, C.C., Marshall, N., McClanahan, T.R., 2013. Evaluating social and ecological vulnerability of coral reef fisheries to climate change. PloS one 8 (9), e74321.
Cinner, J.E., Pollnac, R.B., 2004. Poverty, perceptions and planning: why socioeconomics matter in the management of Mexican reefs. Ocean Coast. Manag. 47 (9–10), 479–493.
Clark, J.S., 2004. Why environmental scientists are becoming Bayesians. Ecol. Lett. 8 (1), 2–14.
Clark, W.C., 2007. Sustainability science: a room of its own. Proc. Natl. Acad. Sci. USA 104 (6), 1737–1738.
Le Cornu, E., Kittinger, J.N., Koehn, J.Z., Finkbeiner, E.M., Crowder, L.B., 2014. Current practice and future prospects for social data in coastal and ocean planning. Conserv. Biol. 28 (4), 902–911.
Deppisch, S., Hasibovic, S., 2011. Social-ecological resilience thinking as a bridging concept in transdisciplinary research on climate-change adaptation. Nat. Hazards 67 (1), 117–127.
Diaz, S., Quétier, F., Cáceres, D.M., Trainor, S.F., Pérez-Harguindeguy, N., Bret-Harte, M.S., Finegan, B., Peña-Claros, M., Poorter, L., 2011. Linking functional diversity and social actor strategies in a framework for interdisciplinary analysis of nature's benefits to society. Proc. Natl. Acad. Sci. USA 108 (3), 895–902.
Ehler, C., 2003. Indicators to measure governance performance in integrated coastal management. Ocean Coast. Manag. 46 (3–4), 335–345.
Fischer, J., Peterson, G.D., Gardner, T.A., Gordon, L.J., Fazey, I., Elmqvist, T., Felton, A., Folke, C., Dovers, S., 2009. Integrating resilience thinking and optimisation for conservation. Trends Ecol. Evol. 24 (10), 549–554.
Fisher, W.H., 2012. Interdisciplinary crafting of the conservation agenda. Conserv. Biol. 26 (5), 949–950.
Folke, C., 2006. Resilience: the emergence of a perspective for social-ecological systems analyses. Glob. Environ. Change-Human Policy Dimensions 16 (3), 253–267.
Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L., Holling, C.S., 2004. Regime shifts, resilience, and biodiversity in ecosystem management. Annu. Rev. Ecol. Evol. Syst. 35 (1), 557–581.
Fox, E., Miller-Henson, M., Ugoretz, J., Weber, M., Gleason, M., Kirlin, J., Caldwell, M., Mastrup, S., 2013. Enabling conditions to support marine protected area network planning: California's Marine Life Protection Act Initiative as a case study. Ocean Coast. Manag. 74, 14–23.
Fulton, E.A., Smith, A.D.M., Smith, D.C., van Putten, I.E., 2011. Human behaviour: the key source of uncertainty in fisheries management. Fish Fish. 12 (1), 2–17.
Gallopín, G., Funtowicz, S., O'Connor, M., Ravetz, J., 2001. Science for the twenty-first century: from Social contract to the scientific core. Int. J. Soc. Sci. 168 (168), 219–229.
Gaspar, C., Bambridge, T., 2008. Territorialités et aires marines protégées à Moorea (Polynésie française). Journal de la Société des Océanistes 1, 231–246.
Gleason, M., Fox, E., Ashcraft, S., Vasques, J., Whiteman, E., Serpa, P., Saarman, E., Caldwell, M., Frimodig, A., Miller-Henson, M., Kirlin, J., Ota, B., Pope, E., Weber, M., Wiseman, K., 2013. Designing a network of marine protected areas in California: achievements, costs, lessons learned, and challenges ahead. Ocean Coast. Manag. 74, 90–101.
Grace, J.B., 2006. Structural Equation Modelling and Natural Systems. Cambridge.
Gunderson, L.H., Holling, C.S., 2002. Panarchy: Understanding Transformations in Human and Natural Systems. Island Press, Washington, DC.
Gurney, G., Cinner, J.E., Ban, N., Pressey, R.L., Pollnac, R., Campbell, S.J., Tasidjawa, S., Setiwan, F., 2014. Poverty and Protected Areas: an Evaluation of a Marine Integrated Conservation and Development Project in Indonesia, vol. 26(8), pp. 98–107.
Gutiérrez, N.L., Hilborn, R., Defeo, O., 2011. Leadership, social capital and incentives promote successful fisheries. Nature 470 (7334), 386–389.
Halpern, B.S., Klein, C.J., Brown, C.J., Beger, M., Grantham, H.S., Mangubhai, S., Ruckelshaus, M., Tulloch, V.J., Watts, M., White, C., Possingham, H.P., 2013. Achieving the triple bottom line in the face of inherent trade-offs among social equity, economic return, and conservation. Proc. Natl. Acad. Sci. USA 110 (15), 6229–6234.
Henly-Shepard, S., Anderson, C., Burnett, K., Cox, L., Kittinger, J., Ka'aumoana, M., 2015. Quantifying household social resilience: a place-based approach in a rapidly transforming community. Nat. Hazards. 75, 343–363. http://dx.doi.org/10.1007/s11069-014-1328-8.
Himes, A.H., 2007. Performance indicators in MPA management: using questionnaires to analyze stakeholder preferences. Ocean Coast. Manag. 50 (5–6), 329–351.
Holling, C.S., 1978. Adaptive Environmental Assessment and Management. Chichester.
Holling, C.S., 2001. Understanding the complexity of economic, ecological, and social systems. Ecosystems 4 (5), 390–405.
Hughes, T.P., Bellwood, D.R., Folke, C., Steneck, R.S., Wilson, J., 2005. New paradigms for supporting the resilience of marine ecosystems. Trends Ecol. Evol. (Personal Ed.) 20 (7), 380–386.
Janssen, M., Bodin, Ö., Anderies, J.M., Elmqvist, T., Ernstson, H., McAllister, R.J.,

Olsson, P., Ryan, P., Bodin, O., 2006. Toward a network perspective of the study of resilience in social-ecological systems. Ecol. Soc. 11 (1), 20.
Jentoft, S., 2000. Legitimacy and disappointment in fisheries management. Mar. Policy 24 (2), 141–148.
Kates, R.W., 2001. Environment and development: sustainability science. Science 292 (5517), 641–642.
Kates, R.W., 2011. What kind of a science is sustainability science? Proc. Natl. Acad. Sci. USA 108 (49), 19449–19450.
Kauneckis, D., Assistant, P., Imperial, M.T., Assistant, P.D., 2005. Collaborative Watershed Governance in Lake Tahoe: an Institutional Analysis.
Kininmonth, S., Beger, M., Bode, M., Peterson, E., Adams, V.M., Dorfman, D., Brumbaugh, D.R., Possingham, H.P., 2011. Dispersal connectivity and reserve selection for marine conservation. Ecol. Model. 222 (7), 1272–1282.
Kininmonth, S., Lemm, S., Malone, C., Hatley, T., 2014. Spatial vulnerability assessment of anchor damage within the great barrier reef world heritage area, Australia. Ocean Coast. Manag. 100, 20–31.
Kittinger, J., Finkbeiner, E., Glazier, E.W., Crowder, L.B., 2012. Human dimensions of coral reef social-ecological systems. Ecol. And Soc. 17 (4), 17.
Kittinger, J.N., Dowling, A., Purves, A.R., Milne, N.A., Olsson, P., 2011. Marine protected areas, multiple-agency management, and monumental surprise in the Northwestern Hawaiian islands. J. Mar. Biol. 2011, 1–17.
Kittinger, J.N., Finkbeiner, E.M., Ban, N.C., Broad, K., Carr, M.H., Cinner, J.E., Gelcich, S., Cornwell, M.L., Koehn, J.Z., Basurto, X., Fujita, R., Caldwell, M.R., Crowder, L.B., 2013. Emerging frontiers in social-ecological systems research for sustainability of small-scale fisheries. Curr. Opin. Environ. Sustain. 5 (3–4), 352–357.
Kittinger, J.N., Koehn, J.Z., Le Cornu, E., Ban, N.C., Gopnik, M., Armsby, M., Brooks, C., Carr, M.H., Cinner, J.E., Cravens, A., D'Iorio, M., Erickson, A., Finkbeiner, E.M., Foley, M.M., Fujita, R., Gelcich, S., Martin, K.S., Prahler, E., Reineman, D.R., Shackeroff, J., White, C., Caldwell, M.R., Crowder, L.B., 2014. A practical approach for putting people in ecosystem-based ocean planning. Front. Ecol. Environ. 12, 448–456, 140915063732004.
Koch, E.W., Barbier, E.B., Silliman, B.R., Reed, D.J., Perillo, G.M., Hacker, S.D., Granek, E.F., Primavera, J.H., Muthiga, N., Polasky, S., Halpern, B.S., Kennedy, C.J., Kappel, C.V., Wolanski, E., 2009. Non-linearity in ecosystem services: temporal and spatial variability in coastal protection. Front. Ecol. Environ. 7 (1), 29–37.
Koehn, J.Z., Reineman, D.R., Kittinger, J.N., 2013. Progress and promise in spatial human dimensions research for ecosystem-based ocean planning. Mar. Policy 42, 31–38.
Koster, F., Mollmann, C., Hinrichsen, H., Wieland, K., Tomkiewicz, J., Kraus, G., Voss, R., Makarchouk, A., Mackenzie, B., Stjohn, M., 2005. Baltic cod recruitment – the impact of climate variability on key processes. ICES J. Mar. Sci. 62 (7), 1408–1425.
Lade, S.J., Tavoni, A., Levin, S.A., Schlüter, M., 2013. Regime shifts in a social-ecological system. Theor. Ecol. 6 (3), 359–372.
Langer, J.S., 2012. Enabling scientific innovation. Sci. (New York, N.Y.) 338 (6104), 171.
Leslie, H., McLeod, K., 2007. Confronting the challenges of implementing marine ecosystem-based management. Front. Ecol. Environ. 5 (10), 540–548.
Levin, S.A., 1998. Ecosystems and the Biosphere as complex adaptive systems. Ecosystems 1 (5), 431–436.
Levin, S.A., Lubchenco, J., 2008. Resilience, robustness, and Marine ecosystem-based management. BioScience 58 (1), 27.
Levin, S., Xepapadeas, T., Crépin, A.-S., Norberg, J., de Zeeuw, A., Folke, C., Hughes, T., Arrow, K., Barrett, S., Daily, G., Ehrlich, P., Kautsky, N., Mäler, K.-G., Polasky, S., Troell, M., Vincent, J.R., Walker, B., 2012. Social-ecological systems as complex adaptive systems: modeling and policy implications. Environ. Dev. Econ. 1–22.
Levine, A.S., Richmond, L.S., 2014. Examining Enabling Conditions for Community-based Fisheries Comanagement: Comparing Efforts in Hawai'i and American Samoa, vol. 19(1).
Lindegren, M., Andersen, K.H., Casini, M., Neuenfeldt, S., 2014. A metacommunity perspective on source – sink dynamics and management: the Baltic Sea as a case study. Ecol. Appl. 24 (7), 1232–1820.
Lison de Loma, T., Osenberg, C.W., Shima, J.S., Chancerelle, Y., Davies, N., Brooks, A.J., 2008. A framework for assessing impacts of Marine protected areas in moorea (French Polynesia) 1. Pac. Sci. 427 (C), 427–438.
Liu, J.G., Dietz, T., Carpenter, S.R., Alberti, M., Folke, C., Moran, E., Pell, A.N., Deadman, P., Kratz, T., Lubchenco, J., Ostrom, E., Ouyang, Z., Provencher, W., Redman, C.L., Schneider, S.H., Taylor, W.W., 2007a. Complexity of coupled human and natural systems. Science 317 (5844), 1513–1516.
Liu, J.G., Dietz, T., Carpenter, S.R., Folke, C., Alberti, M., Redman, C.L., Schneider, S.H., Ostrom, E., Pell, A.N., Lubchenco, J., Taylor, W.W., Ouyang, Z.Y., Deadman, P., Kratz, T., Provencher, W., 2007b. Coupled human and natural systems. Ambio 36 (8), 639–649.
Lowe, C.D., Gilbert, A.J., Mee, L.D., 2014. Human–environment interaction in the Baltic Sea. Mar. Policy 43, 46–54.
MA, 2005. Ecosystems and Human Well-being: Biodiversity Synthesis (Washington, DC).
Mace, G.M., 2014. Whose conservation? Science 345 (6204), 1558–1560.
MacKenzie, B.R., Ojaveer, H., Eero, M., 2011. Historical ecology provides new insights for ecosystem management: eastern Baltic cod case study. Mar. Policy 35 (2), 266–270.
MacNeil, M. Aaron, 2015. Recovery potential of the world's coral reef fishes. Nature 520. 7547, 341–344.
McDonald, A., Little, L., Gray, R., Fulton, E., Sainsbury, K., Lyne, V., 2008. An agent-based modelling approach to evaluation of multiple-use management strategies for coastal marine ecosystems. Math. Comput. Simul. 78 (2), 401–411.
McLeod, K., Leslie, H., 2009. Ecosystem-based Management for the Oceans. Island Press, Washington, D.C.
McLeod, K.L., Lubchenco, J., Palumbi, S.R., Rosenberg, A.A., 2005. Scientific Consensus Statement on Marine Ecosystem-based Management. The Communication Partnership for Science and the Sea (COMPASS). http://www.compassonline.org/pdf_files/EBM_Consensus_Statement_v12.pdf. Signed by 221 academic scientists and policy experts with relevant expertise.
Mills, M., Pressey, R.L., Ban, N.C., Foale, S., Aswani, S., Knight, A.T., 2013a. Understanding characteristics that define the feasibility of conservation actions in a common pool marine resource governance system. Conserv. Lett. 6 (6), 418–429.
Mills, M., Pressey, R.L., Ban, N.C., Foale, S., Aswani, S., Knight, A.T., Armitage, D., 2013b. Understanding Characteristics that Define the Feasibility of Conservation Actions in a Common Pool Marine Resource Governance System, pp. 418–429.
Milner-Gulland, E.J., McGregor, J.A., Agarwala, M., Atkinson, G., Bevan, P., Clements, T., Daw, T., Homewood, K., Kumpel, N., Lewis, J., Mourato, S., Palmer Fry, B., Redshaw, M., Rowcliffe, J.M., Suon, S., Wallace, G., Washington, H., Wilkie, D., 2014. Accounting for the impact of conservation on human well-being. Conserv. Biol. J. Soc. Conserv. Biol. 00 (0), 1–7.
Möllmann, C., Diekmann, R., Müller-Karulis, B., Kornilovs, G., Plikshs, M., Axe, P., 2009. Reorganization of a large marine ecosystem due to atmospheric and anthropogenic pressure: a discontinuous regime shift in the Central Baltic Sea. Glob. Change Biol. 15 (6), 1377–1393.
Niiranen, S., Yletyinen, J., Tomczak, M.T., Blenckner, T., Hjerne, O., Mackenzie, B.R., Müller-Karulis, B., Neumann, T., Meier, H.E.M., 2013. Combined effects of global climate change and regional ecosystem drivers on an exploited marine food web. Glob. change Biol. 19 (11), 3327–3342.
Olsson, P., Folke, C., Hughes, T.P., 2008. Navigating the transition to ecosystem-based management of the Great Barrier Reef, Australia. Proc. Natl. Acad. Sci. USA 105 (28), 9489–9494.
Österblom, H., Hansson, S., Larsson, U., Hjerne, O., 2007. Human-induced trophic cascades and ecological regime shifts in the Baltic Sea. Ecosystems 877–889.
Österblom, H., Merrie, A., Metian, M., Boonstra, W.J., Blenckner, T., 2013. Modeling Social–Ecological scenarios in Marine systems. BioScience 63 (9), 735–744.
Ostrom, E., 2007. A diagnostic approach for going beyond panaceas. Proc. Natl. Acad. Sci. USA 104 (39), 15181–15187.
Ostrom, E., 2009. A general framework for analyzing sustainability of social-ecological systems. Science 325 (5939), 419–422.
Pajaro, M.G., Mulrennan, M.E., Alder, J., Vincent, A.C.J., 2010. Developing MPA effectiveness indicators: comparison within and across stakeholder groups and communities. Coast. Manag. 38 (2), 122–143.
Parrott, L., 2002. Complexity and the limits of ecological engineering. Trans. ASAE 45 (5), 1–6.
Parrott, L., Chion, C., 2012. Agents, individuals, and networks: modeling methods to inform natural resource management in regional landscapes. Ecol. Soc. 17 (3), 32.
Parrott, L., Meyer, W.S., 2012. Future landscapes: managing within complexity. Front. Ecol. Environ. 10 (7), 382–389.
Plummer, R., Armitage, D., 2007. A resilience-based framework for evaluating adaptive co-management: linking ecology, economics and society in a complex world. Ecol. Econ. 61 (1), 62–74.
Poe, M.R., Norman, K.C., Levin, P.S., 2014. Cultural dimensions of socioecological systems: key connections and guiding principles for conservation in coastal environments. Conserv. Lett. 7 (3), 166–175.
Polasky, S., Carpenter, S.R., Folke, C., Keeler, B., 2011. Decision-making under great uncertainty: environmental management in an era of global change. Trends Ecol. Evol. 26 (8).
Pollnac, R., Christie, P., Cinner, J.E., Dalton, T., Daw, T.M., Forrester, G.E., Graham, N.A.J., McClanahan, T.R., 2010. Marine reserves as linked social-ecological systems. Proc. Natl. Acad. Sci. USA 107 (43), 18262–18265.
Pomeroy, R., Watson, L., Parks, J., Cid, G., 2005. How is your MPA doing? A methodology for evaluating the management effectiveness of marine protected areas. Coast. Manag. 48, 485–502.
Van Putten, I., Lalancette, A., Bayliss, P., Dennis, D., Hutton, T., Norman-López, A., Pascoe, S., Plagányi, E., Skewes, T., 2013. A Bayesian model of factors influencing indigenous participation in the Torres Strait tropical rocklobster fishery. Mar. Policy 37, 96–105.
Rodrigo, A., Alberts, S., Cranston, K., Kingsolver, J., Lapp, H., McClain, C., Smith, R., Vision, T., Weintraub, J., Wiegmann, B., 2013. Science incubators: synthesis centers and their role in the research ecosystem. PLoS Biol. 11 (1), e1001468.
Salvat, B., Pailhe, C., 2002. Islands and coral reefs, population and culture, economy and tourism: world view and a case study of French Polynesia. Page 502pp.. In: di Castri, F., Balaji, V. (Eds.), Tourism, Biodiversity and Information. Backhuys Publishers, Leiden.
Schlüter, M., Hinkel, J., 2014. Application of the SES framework for model-based analysis of the dynamics of social-ecological systems. Ecol. … 19 (1).
Smith, A., Stirling, A., 2010. The politics of social-ecological resilience and sustainable socio-technical transitions. Ecol. Soc. 15 (1), 13.
Stephanson, S.L., Mascia, M.B., 2014. Putting people on the map through an approach that integrates social data in conservation planning. Conserv. Biol. 00 (0) n/a–n/a.
Turner, B.L., Kasperson, R.E., Matson, P.A., McCarthy, J.J., Corell, R.W., Christensen, L., Eckley, N., Kasperson, J.X., Luers, A., Martello, M.L., et al., 2003a. A framework for vulnerability analysis in sustainability science. Proc. Natl. Acad. Sci. 100 (14), 8074.
Turner, B.L., Lambin, E.F., Reenberg, A., 2007. The emergence of land change science

for global environmental change and sustainability. Proc. Natl. Acad. Sci. USA 104 (52), 20666–20671.
Turner, B.L., Matson, P.A., McCarthy, J.J., Corell, R.W., Christensen, L., Eckley, N., Hovelsrud-Broda, G.K., Kasperson, J.X., Kasperson, R.E., Luers, A., Martello, M.L., Mathiesen, S., Naylor, R., Polsky, C., Pulsipher, A., Schiller, A., Selin, H., Tyler, N., 2003b. Illustrating the coupled human-environment system for vulnerability analysis: three case studies. Proc. Natl. Acad. Sci. USA 100 (14), 8080–8085.
Uusitalo, L., 2007. Advantages and challenges of Bayesian networks in environmental modelling. Ecol. Model. 203 (3–4), 312–318.
Varjopuro, R., Andrulewicz, E., Blenckner, T., Dolch, T., Heiskanen, A., Pihlajamäki, M., 2014. Coping with persistent environmental problems: systemic delays in reducing eutrophication of the Baltic Sea. Ecol. Soc. 19 (4), 48.
Wilson, J.A., 2006. Matching social and ecological systems in complex ocean fisheries. Ecol. Soc. 11 (1).
Xu, L., Marinova, D., 2013. Resilience thinking: a bibliometric analysis of socio-ecological research. Scientometrics 911–927.
Young, O., 2006. Vertical interplay among scale-dependent environmental and resource regimes. Ecol. Soc. 11 (1).
Young, O., Berkhout, F., Gallopin, G., Janssen, M., Ostrom, E., Vanderleeuw, S., 2006. The globalization of socio-ecological systems: an agenda for scientific research. Glob. Environ. Change 16 (3), 304–316.