Ocean & Coastal Management 112 (2015) 25–35

Contents lists available at ScienceDirect

Ocean & Coastal Management

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

Review

Improving knowledge exchange among scientists and decision-makers to facilitate the adaptive governance of marine resources: A review of knowledge and research needs

C. Cvitanovic [a, b, *], A.J. Hobday [b, c], L. van Kerkhoff [a], S.K. Wilson [d, e], K. Dobbs [f], N.A. Marshall [g]

[a] Fenner School of Environment and Society, Australian National University, Canberra ACT, 2600, Australia
[b] Oceans and Atmosphere Flagship, CSIRO, Hobart, Tasmania 7001, Australia
[c] Centre for Marine Socioecology, University of Tasmania, Battery Point, Tasmania 7004, Australia
[d] Marine Science Program, Department of Parks and Wildlife, Kensington, WA, Australia
[e] Oceans Institute, University of Western Australia, Crawley, WA 6009, Australia
[f] Great Barrier Reef Marine Park Authority, Townsville, Qld 4810, Australia
[g] Land and Water Flagship, CSIRO, Based at James Cook University, Townsville, Qld 4811, Australia

ARTICLE INFO

Article history:
Received 5 February 2015
Received in revised form
1 May 2015
Accepted 6 May 2015
Available online 15 May 2015

Keywords:
Knowledge exchange
Knowledge transfer
Decision-making
Institutional barriers
Institutional innovation
Enabling environment
Research needs

ABSTRACT

The science-based management of natural resources requires knowledge exchange between scientists and environmental decision-makers, however, this exchange remains a significant challenge. Rather, evidence suggests that decision-makers rely on individual experience or other secondary sources of knowledge in isolation from scientific evidence when formulating decisions, potentially compromising the effectiveness of their decisions. As a result a new field of research broadly characterised as 'knowledge exchange' has emerged, focused largely on identifying and overcoming the barriers to knowledge exchange among scientists and decision-makers. More recently knowledge exchange research has also begun to explore the relationship between science and decision-making specifically in relation to marine ecosystems and resources. The aim of this paper is to review the literature in relation to knowledge exchange for natural resource management, with a focus on recent evidence in relation to the management of marine resources. This review identifies critical barriers inhibiting knowledge exchange among marine scientists and decisions-makers, such as the inaccessibility of science to decision-makers as well as institutional barriers that limit the extent to which scientists and decision-makers can prioritise knowledge exchange activities. Options for overcoming these barriers, such as novel approaches to knowledge exchange (e.g. – knowledge co-production, knowledge brokers and boundary organisations) and the enabling environments and institutional reforms needed to complement efforts to improve knowledge exchange, are also identified. This review concludes by articulating the gaps in our understanding of knowledge exchange, to help guide future research in this field and improve the sustainable management of marine resources.

1. Introduction

Ecological goods and services provided by marine systems are critical for human welfare, however, the sustainable management of these resources has been a topic of continued concern in part due to the complex and dynamic socio-ecological systems in which they are imbedded (e.g. – Berkes et al., 2003; Mahon et al., 2008; de Jonge et al., 2012). As a result scholars and resource managers alike have called for new flexible, integrated, holistic forms of management and governance that can deal with the complexity of social-ecological systems and their associated services (Berkes and Folke, 1998; Gunderson and Holling, 2002; Hughes et al., 2005). Calls for more effective approaches to resource management have also been fuelled by burgeoning factors such as population growth, coastal development and climate change, which render the

* Corresponding author. Oceans and Atmosphere Flagship, CSIRO, Hobart, Tasmania, 7001, Australia.
E-mail address: christopher.cvitanovic@csiro.au (C. Cvitanovic).

http://dx.doi.org/10.1016/j.ocecoaman.2015.05.002

conditions under which management must operate increasingly uncertain and unpredictable (e.g. – Millar et al., 2007; Hallegatte, 2009).

One framework that has been proposed to be capable of dealing with the uncertainty associated with complex socio-ecological systems is that of adaptive governance (Österblom and Folke, 2013; Chaffin et al., 2014). Adaptive governance is a concept derived from institutional theory that focuses on the evolution of formal and informal institutional arrangements for the management of shared assets, such as a set of environmental assets that provide ecosystems services (reviewed Nelson et al., 2008). Specifically, adaptive governance refers to society's capacity to understand and respond to environmental and social feedback in the context of change and uncertainty, to sustain and enhance the resistance and resilience of desirable ecosystems (Berkes and Folke, 1998). As such, adaptive governance involves the capacity to 1) understand environmental change, 2) use this information to inform decision making, 3) act on decisions in a manner that sustains the resistance and resilience of desirable ecosystem states and 4) review and adapt decisions as new information becomes available (Evans et al., 2011). Governing resources adaptively, therefore, is a knowledge intensive endeavour (e.g. – MEA, 2005) requiring an understanding of social-ecological systems in their full complexity so as to respond to feedback from the system across both spatial and temporal scales (Berkes et al., 2003; Berkes, 2009).

While multiple sources of knowledge can, and should, inform the management of environmental resources (Raymond et al., 2010), the importance of incorporating primary science into decision-making processes is widely recognised. In this regard, primary science is defined as knowledge that is generated through formalised processes such as through research and/or the application of scientific methodology (Turnbull, 1997; Raymond et al., 2010) and contrasts with constructivist knowledge (Dessler, 1999; Kukla, 2000). Primary science is advocated for its ability to determine environmental baselines, improve our understanding of the likelihood and potential impacts of natural and anthropogenic disturbance to the system and predict the implications of these changes to society (e.g. – Meinke et al., 2009; Cook et al., 2010). For example, biophysical science is important for predicting the likely consequences of disturbances to environmental assets, and testing the effectiveness of possible management responses, thus allowing proactive rather than reactive management actions to be taken (Evans et al., 2011). Primary biophysical science alone, however, cannot establish the societally acceptable thresholds, which is an important element of decision making. Thus, there is a growing recognition that the social and economic sciences are critical for informing the sustainable management of ecological goods and services (Endter-Wada et al., 1998; Mascia, 2003). For example, the social sciences are important for elucidating the cultural beliefs, values, norms and rules of local communities to serve as the foundation of formal laws and regulations that will govern protected areas, thus increasing their likely success (Mascia, 2003). Accordingly, incorporating social and economic science, in combination with biophysical science, into the decision-making processes for natural resource management is now widely advocated (e.g. – Aswani and Hamilton, 2004; Salick and Ross, 2009; de Jonge et al., 2012; Naess, 2013; Glass et al., 2015).

Despite widespread recognition regarding the importance of integrating primary science into the decision-making process for natural resource governance and an increase in the number of applied scientific publications (Ormerod et al., 2002), an implementation gap between science and natural resource management remains (Sutherland et al., 2004; Knight et al., 2008; Kirchhoff, 2013). Specifically in relation to marine systems it was recently shown that although marine resource managers and scientists have similar research interests and identify similar future research priorities, decision-makers may be unaware of the full breadth of existing scientific information that they could use to inform their decision-making processes (Cvitanovic et al., 2013). Subsequently, marine resource decision-makers from a range of agencies and locations were found to rely on individual experiences or other secondary sources of information when developing and implementing conservation actions in isolation from scientific evidence (Cvitanovic et al., 2014a; Addison et al., 2015). This pattern potentially compromises the effectiveness of their decision with adverse flow-on effects to the people and communities who depend on the goods and services provided by marine systems. Accordingly, improving knowledge-exchange among marine scientists and decision-makers is fundamental for supporting the adaptive governance of marine resources and to ensure their sustainable management for future generations (de Jonge and Giebels, 2015). To advance that goal, we provide a narrative review based on published literature describing knowledge exchange among environmental scientists and decision-makers, drawing heavily on an emergent and growing body of literature specifically focused on understanding this relationship in the marine resource management sector. Doing so we identify ongoing barriers to knowledge exchange, the options and enabling environments required to overcome these barriers, and key gaps in our understanding that must be addressed if we are to improve knowledge exchange among marine scientists and decision-makers.

2. An introduction to knowledge exchange

In undertaking this review it is first instructive to provide a brief introduction to the concept of knowledge exchange. Indeed, understanding the relationship between knowledge and decision-making is not new, but rather a long-standing question of academic interest with deep roots in philosophy (Rich, 1979; Majone, 1989). In the past 15 years, however, this relationship has become increasingly prominent in the scientific literature in recognition of the need to converge diverse but complementary disciplinary approaches and views in response to complex problems across a wide range of sectors such as health, education, business and environmental management (Fig. 1). Specifically in the conservation and resource management sectors, knowledge exchange is increasingly recognised as a key factor facilitating the social, environmental and economic impacts of research (Fazey et al., 2013), thus improving the sustainable management of natural systems and the goods and services they provide, and in turn ensuring the safety and well-being of the people that depend on them.

Throughout the literature there are multiple definitions of knowledge exchange and multiple terms used to describe knowledge exchange processes (reviewed by Fazey et al., 2013). A common recognition, however, is that knowledge exchange describes the interchange of knowledge between research users and "scientific" producers (Mitton et al., 2007). The concept of knowledge exchange, therefore, encompasses all facets of knowledge production, sharing, storage, mobilization, translation and use (Best and Holmes, 2010). As such, when done successfully it is believed that knowledge exchange increases the likelihood that knowledge and evidence will be used in policy and practice decisions, thus increasing the success of those decisions in meeting their objectives.

In a recent systematic review of the knowledge exchange literature relevant to the health sector, Contandriopoulos et al. (2010) identify how knowledge exchange processes primarily occur at two complementary levels. The first, termed *autonomy*, refers to the fact that the potential users of knowledge are typically sovereign in their capacity to mobilise knowledge and subsequently, modify

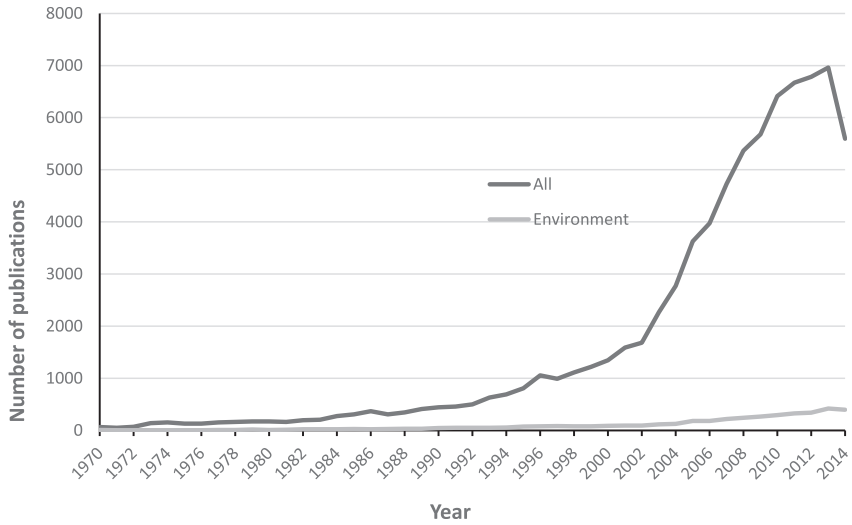

Fig. 1. Results of a SCOPUS search using the key words 'knowledge exchange' or 'knowledge transfer' or 'knowledge sharing', showing the total number of peer-reviewed manuscripts published since 1970 across any scientific discipline, and limited to environmental sectors. Note the decline in 2014 is due to delays in indexing papers from this most recent year.

their practices. A similar relationship is also recognised in the literature on sustainable development, whereby historically the producers and users of knowledge were considered as two independent groups (reviewed by Van Kerkhoff and Lebel, 2006). Under such relationships the transfer of knowledge among scientists and decision-makers occurs following the knowledge-deficit model, whereby scientists as the producers of knowledge are responsible for making it available to potential end-users (Stocklmayer, 2013). Under this linear and uni-directional model, one may argue that publishing in peer-reviewed journals adequately brings scientific knowledge into the public domain, and thus is the end of the researcher's responsibility. Others argue that scientists and their organisations have an ethical responsibility to make a more concerted effort to better engage with and communicate to end-users (Lacey et al., 2015).

In contrast, Contandriopoulos et al. (2010) identify a second level at which knowledge exchange processes can occur. Termed *interdependency*, this model recognises high levels of interdependency and interconnectedness among all participants. As such a defining feature of this model is that participants do not have autonomy or power to translate scientific knowledge into practice independently. Rather, all individuals in this model are embedded in systematic relationships in which the generation and use of knowledge is mediated by a range of factors such as the contexts in which they operate or the institutional norms and values by which they are constrained (e.g. – Jordan and Maloney, 1997; Russell et al., 2008). Indeed, such dependencies have been documented in relation to the management of natural systems and resources (e.g. – Jantarasami et al., 2010; Dowd et al., 2014), including marine resources (Cvitanovic et al., 2014b, 2015). Furthermore, *interdependency* explicitly recognises that all participants in knowledge exchange, be they knowledge producers, users or intermediaries, have their own experiential knowledge that can contribute to the process of knowledge exchange (Fazey et al., 2006). Accordingly, *interdependency* emphasises the need for the interactive and iterative two-way exchange of knowledge among scientists and decision-makers (Roux et al., 2006; Spilsbury and Nasi, 2006; Cornell et al., 2013).

While the literature on knowledge exchange across different sectors is expansive, knowledge exchange in relation to natural resource management has only recently been recognised as a research endeavour (Fig. 1). As a result the literature on knowledge exchange in relation to natural resource management is significantly less developed, with little connection to research from other fields, thus limiting our ability to improve knowledge exchange among scientists and decision-makers (reviewed by Fazey et al., 2013). To date, most research seeking to understand knowledge exchange in relation to natural resource management has focused on two specific areas; (i) identifying the barriers that prevent efficient and effective knowledge exchange, and (ii) developing frameworks for overcoming these barriers. This literature is reviewed in the following two sections, with a focus on recent advances in knowledge exchange in relation to the management of marine resources.

3. Barriers to knowledge exchange between scientists and decision-makers

3.1. Cultural differences

Throughout the knowledge exchange literature cultural differences between environmental scientists and decision-makers is widely accepted as a key factor undermining effective knowledge exchange among the two groups (e.g. – Cullen, 1990; Norton, 1998; Kinzig, 2001; Briggs, 2006; Roux et al., 2006). For example, in general scientists construct theories, test hypotheses and refine conceptual models over time based on rigorous methodological approaches to withstand the highest degrees of public scrutiny and criticism. In turn, in the world of decision-making science is just one point of view, and frequently not the most influential (Cook et al., 2012). Rather, decision-makers are driven by a range of political, economic and social drivers that reflect other societal issues (e.g. – Policansky, 1998). As such decision-makers often manage a process of negotiation and compromise among the competing interests of diverse stakeholders. While scientists generate data to advance knowledge, decision-makers may mobilise specific information to support a particular agenda without always giving consideration to the full range of available evidence or detailed public debate (Briggs, 2006). These cultural differences are believed to lead to friction and frustration among scientists and decision-makers alike, and can act to undermine efforts to improve knowledge exchange and collaboration (Cortner, 2000; Roux et al., 2006; McNie, 2007).

3.2. Institutional barriers

In many cases cultural differences are also reinforced by institutional (dis-)incentives and structures, further preventing and undermining effective knowledge exchange and collaboration among scientists and decision-makers (Acheson, 2006; Briggs, 2006; Shanley and López, 2009). This is particularly true in relation to marine resource management. For example, a recent survey of 78 marine scientists from 19 individual research organisations found that while engaging with decision-makers was important to marine scientists on a personal level, a range of institutional barriers prevent this from happening (Cvitanovic et al., 2015). These included inadequate measures of science impact that do not account for engagement activities, a lack of organisational support for engagement activities, insufficient time to conduct engagement activities in addition to other responsibilities and a lack of funding to support engagement activities. Some outreach activities that typically constitute the type of work involved in knowledge exchange activities are not widely accepted as legitimate forms of scholarship (e.g –Jacobson et al., 2004; Shanley and López, 2009). Scientists report that some marine research institutions are perpetuating a culture whereby action-orientated research that actively engages decision-makers is under-valued (Cvitanovic et al., 2015). Likewise, decision-makers face a range of institutional barriers that prevent knowledge exchange activities from occurring, as well as leading them to feel disempowered to act or take action (e.g – Lachapelle et al., 2003; Brown and Farrelly, 2009; Jantarasami et al., 2010). For example, a recent survey of Australian marine protected area (MPA) managers identified the government as a key barrier undermining progress towards climate adaptation, stating that adaptation lacks proper consideration by governments, it is not a current priority, and receives insufficient government funding (Cvitanovic et al., 2014b).

3.3. Science in-accessibility

A number of structural impediments related to science in-accessibility have also been documented and suggested as a key barrier preventing knowledge exchange among natural resource scientists and decisions-makers (Fazey et al., 2005), thus limiting the uptake of primary science by decision-makers. A recent review of 222 published scientific papers across a four year period in relation to MPA management found that it takes more than three years for scientific articles to be published following data collection (Cvitanovic et al., 2014a). Information may thus be out of date and less useful to decision-makers by the time it is made available (Linklater, 2003). Furthermore, over half of this scientific literature was not freely available to marine decision-makers, due to scientific journals requiring subscription to access the contents. Even when scientific literature was freely available to decision-makers, only 19% of scientific articles provided clear outcomes that were considered relevant to MPA managers. Clearly, the inaccessibility of scientific information to marine decision-makers is also a key factor undermining the integration of science into the decision-making process for the management of marine resources.

3.4. Conventional approaches to knowledge exchange

Conventional approaches to knowledge exchange have also been identified as a key factor limiting the integration of science into the decision-making process for natural resource management. As described in Section 2, under the *autonomy* model of knowledge exchange scientists and decision-makers are viewed as two independent groups, whereby scientists as the producers of knowledge are responsible for making that knowledge available to end-users. Historically this led to linear and uni-directional knowledge transfer processes, and as a result efforts at knowledge transfer were focused on traditional modes of communication whereby scientific information is packaged for broad dissemination that would be palatable by diverse audiences (Bensaude-Vincent, 2009). In doing so, these approaches fail to acknowledge and integrate the diversity of social contexts among end-users or the multiplicity of actors involved, preventing the uptake of information into the decision-making process (Stocklmayer, 2013). For example, Grorud-Colvert et al. (2010) noted the difficulties in providing relevant and understandable information to all stakeholders through a single media/approach and identified this as one of the key challenges of communicating MPA science to diverse audiences in California. Accordingly, numerous researchers have called for contemporary approaches to knowledge sharing that emphasise the need for the two-way exchange of information, in appreciation of the complex, multi-faceted and dynamic relationships between science-based knowledge and decision-making (e.g. – Roux et al., 2006; Van Kerkhoff and Lebel, 2006; Cornell et al., 2013).

3.5. Personal perceptions and worldviews

Finally, several authors have suggested that personal perceptions and biases can undermine effective knowledge exchange among scientists and decision-makers. For example, while scientific knowledge is often presented to decision-makers in an explicit form (e.g. – through media such as written reports or oral presentations), the information being presented is interpreted by individuals who make sense from that information based on their own personal knowledge and past experiences (Longino, 1990; Fazey et al., 2006; Leviston and Walker, 2012). This can be particularly problematic when dealing with highly popularised and contentious environmental issues such as climate change which attract significant media attention and public interest, resulting in most individuals having preconceived perceptions and beliefs which may prevent the integration of the information into the decision-making process (Leviston and Walker, 2012). As discussed by Raymond et al. (2010), this implies that knowledge, including primary scientific knowledge, is inherently personal with different individuals interpreting the same information in different ways, affecting the extent to which it is utilised in decision-making processes.

4. Overcoming barriers to knowledge exchange

4.1. New models of knowledge exchange

While the barriers preventing the integration of science into the decision-making process for natural resource management, including the management of marine resources, have been well documented, the solutions remain less certain. Cash et al. (2003), however, observed that decision-makers are more likely to use scientific research in the decision-making process when it is considered salient, credible and legitimate. In this case, salience refers to the extent to which the outcomes of scientific research are relevant to decision-makers, taking into account the specific contexts in which they operate and information needs that they require (e.g. – Cash and Moser, 2000). Secondly, for scientific evidence to be credible it must be perceived by the user to be accurate, valid and of high quality (Cash and Buizer, 2005). Finally, scientific knowledge must be considered legitimate, in that those who produce the information must be seen as free from bias, thus increasing the extent to which the information will be trusted, and therefore used, by the end-user (Deelstra et al., 2003). Achieving all

three of these elements represents a significant challenge, however, Cash et al. (2003) argued that the likelihood of success is enhanced via the implementation of collaborative and participatory approaches to knowledge exchange and scientific research (also see Reed, 2008; Evely et al., 2011; Clarke et al., 2013; Fulton et al., 2015).

In response to the need for innovative and collaborative approaches to knowledge exchange, several novel approaches have been identified and developed in the scientific literature. Of these, perhaps the most widely advocated approach is knowledge *co-production* (reviewed by Van Kerkhoff and Lebel, 2015) (Fig. 2a). Under this approach, managers actively participate in scientific research programs from the onset, collaborating with researchers throughout every aspect of the study including design, implementation and analysis. Including decision-makers in research programs in this manner ensures that decision-makers develop a strong understanding of the research content, as well as developing a strong sense of ownership in the research, which they can then communicate more broadly within their organisation, raising the awareness of others. Indeed, numerous examples of co-produced marine science already exist (e.g. – Ceccarelli et al., 2011; Dale and Armitage, 2011; Hoey et al., 2011; Underwood et al., 2013; Van der Molen et al., 2015), demonstrating increased awareness among scientists regarding the importance of including decision-makers in research programs. Furthermore, widespread efforts to encourage and facilitate the co-production of knowledge among marine decision-makers and scientists are already underway, for example, through collaborative identification of knowledge needs by scientists and managers (e.g. – Wilson et al., 2010; Beger et al., 2011; Cvitanovic et al., 2013).

Improving knowledge exchange among scientists and decision-makers can also be achieved by *embedding* scientists in decision-making agencies (Fig. 2b). For example, Cook et al. (2013a) argue that permanently *embedding* research scientists within organisations dominated by decisions-makers will improve the likelihood that priority knowledge gaps will answered, with the information quickly spreading among decision-makers and informing decisions. There are several examples of marine decision-making organisations embedding marine research scientists within their organisations, such as the Western Australian Department of Parks and Wildlife in Australia and the National Oceanic and Atmospheric Administration (NOAA) in the United States (Simpson, 2008). In the same way, embedding a decision-maker within a scientific organisation, for example as a short term professional development opportunity, will also create increased opportunities for knowledge exchange to occur.

Another approach to improve collaboration and knowledge exchange among marine scientists and decision-makers is through the use of knowledge brokers (Fig. 2c). While the exact role and function of knowledge brokers are conceptualized and operationalised differently in various sectors and settings, the key feature of such a role is to facilitate the exchange of knowledge between and among various stakeholders, including researchers, practitioners, and policy makers (reviewed by Meyer, 2010). To achieve this knowledge brokers are typically embedded within research teams or institutions and act as intermediaries that develop relationships and networks with, among, and between producers and users of knowledge, to facilitate the exchange of knowledge among this network (Michaels, 2009). When implemented effectively, knowledge brokers are believed to have the ability to facilitate organisational change by removing barriers to evidence-based decision-making, and promoting a culture that values the use of the best available science in policy and practice (Dobbins et al., 2009). Development of networks such as those developed by knowledge brokers can be more important than the existence of formal institutions for the effective management of environmental assets (Scholz and Wang, 2006). These strong social networks have been shown to improve collaborative governance processes by facilitating the generation, acquisition and diffusion of different types of knowledge and information in relation to the ecosystem of concern (Crona and Bodin, 2006).

Finally, boundary organisations have been identified as a novel approach to improve knowledge exchange among producers and users of scientific knowledge (Cook et al., 2013a). Like knowledge brokers, boundary organisations facilitate communication and knowledge exchange among diverse networks of stakeholders. However, unlike knowledge brokers boundary organisations are not typically embedded within research teams of organisations but are established as a separate entity (Fig. 2d), thus more effectively representing both sides across the boundary (i.e – science and decision-making) while maintaining credibility through independence (Guston, 2001). In this way, boundary organisations can unite groups that may otherwise have strained relationships (for example, based on the cultural differences between scientists and decision-makers – section 3) to enhance evidence-based decision-making. Boundary organisations prove particularly effective when dealing with a specific issue in a specific location (Osmond et al.,

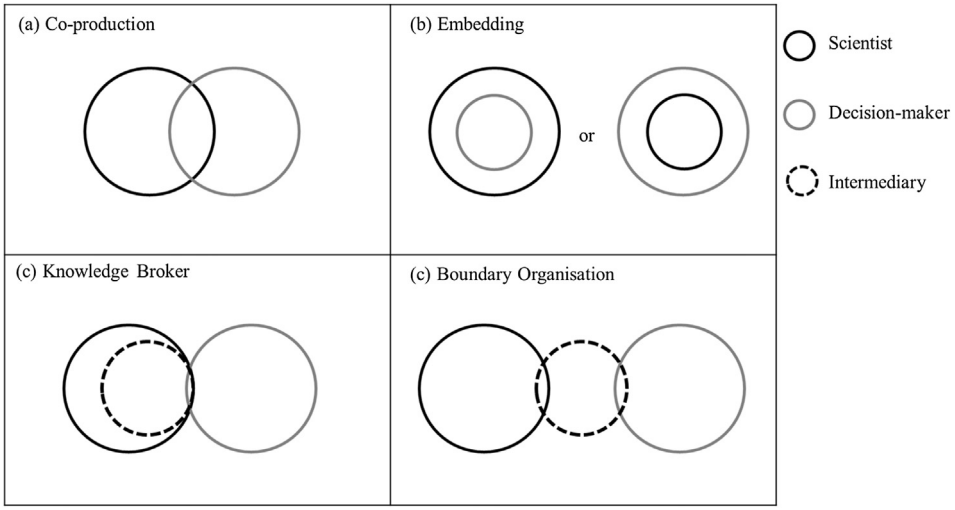

Fig. 2. Conceptual diagram outlining the four primary models believed to increase knowledge exchange among scientists and decision-makers.

2010). An extensive body of literature outlining the potential value of boundary organisations in relation to natural resource management already exists, and recent empirical evidence to support these claims in the environmental sector has been provided (Crona and Parker, 2012; Shaw et al., 2013). A successful marine example has been the establishment of the California Ocean Science Trust, a non-for-profit boundary organisation mandated to support ocean and coastal management decisions with the best available science. Recent evidence from Pietri et al. (2011) highlights the potential importance of this organisation, particularly when dealing with controversial issues such as those associated with the oil and gas sectors or climate change. Accordingly, future investment in these boundary organisations is likely to improve knowledge exchange between marine resource managers and decision-makers in the future.

4.2. Improved access to scientific information

To overcome the documented barriers associated with the inaccessibility of science to decision-makers, and allow a more proactive and systematic rather than a responsive approach to crisis-driven and standard policy-development and management, several authors have advocated for the development of systematic literature reviews in relation to natural resource management (e.g. – Pullin and Knight, 2001; Fazey et al., 2004; Sutherland et al., 2004). As described by Cook et al. (2013b), this practice is believed to help decision-makers manage the rapid increase in available evidence by collating (via a systematic search of the available literature), filtering (identifying credible sources of information), synthesizing (providing a critical analysis of the body of evidence to determine the best decision) and disseminating the evidence to all potential end-users in a freely accessible and understandable format. This approach has proven very effective in providing synthesis for the medical and health sector. For example, the non-for-profit Cochrane Collaboration was established in the UK specifically to help promote evidence-informed health decision-making by producing high-quality, relevant, accessible systematic reviews and other synthesised research evidence (reviewed by Higgins and Green, 2008). This is achieved through a global and independent network of health practitioners, researchers, patient advocates and other members of society who collaborate to produce credible, accessible health information that is free from commercial sponsorship and other conflicts of interest. In doing so the Cochrane Collaboration is now considered a fundamentally important source of knowledge to guide health care providers globally in health practice and medical interventions.

While 'narrative' review papers are routinely published in relation to marine systems and span a range of topics, they are not developed in a systematic manner to address concerns relating to science inaccessibility (Cvitanovic et al., 2014a). As described by Roberts et al. (2006), systematic reviews are a scientific investigation in themselves, in that they have pre-determined methodologies and protocols relating to the review process in its entirety. For example in the Cochrane Collaboration this includes protocols in relation to: the formulation of the research question; the methodology for locating, selecting and analysing studies; the analysis of the results; the interpretation of the final outputs; and the ways in which the key messages are conveyed through the reviews (Higgins and Green, 2008). In contrast, 'narrative' reviews are limited in their usefulness as they typically only provide a qualitative assessment of a research topic based on the experience and personal judgments of the authors. This not only diminishes the credibility of the review for informing decisions, it also increases the likelihood of individual biases impacting the final recommendations, thus reducing the legitimacy of the final product. As such, if review papers are to more effectively assist marine resource decision-makers to stay abreast of the expanding and diverse relevant scientific literature, a more concerted effort to establish a similar protocol to the Cochrane Collaboration is needed.

4.3. Enabling conditions to improve knowledge exchange

Recent studies have also begun to identify the enabling conditions that are needed to overcome the institutional barriers inhibiting knowledge exchange among marine scientists and decision-makers. Specifically, these studies have identified the need for institutional innovation by research institutions, research funders and decision-making agencies alike, to promote a culture whereby knowledge exchange activities are legitimised as core business and recognised and rewarded appropriately (Lacey et al., 2015). Indeed, lack of progress towards the sustainable management of natural resources is widely attributed to institutional failure and inadequacy (Dovers, 2001; Acheson, 2006; Brown and Farrelly, 2009). Thus, in undertaking the innovations described in this section the barriers inhibiting knowledge exchange will be reduced, allowing for improved exchange of knowledge, for example, via the mechanisms outlined in Sections 4.1 and 4.2 (Fig. 3).

For research organisations, this should include formally recognising engagement and communication activities as a core component of a scientist's role, and thus supporting these activities with both dedicated funding and time allocations (Shanley and López, 2009; Cvitanovic et al., 2015) (Fig. 3a). In turn, marine scientists should also be rewarded for engagement and outreach activities alongside traditional metrics of science impact such as peer-reviewed publications (Butler, 2008). Finally, research institutions could establish formal mentoring programs to help develop engagement and communication skills in early career marine scientists (Cvitanovic et al., 2015). This can act as a catalyst for career success in early career professionals with benefits extending to enhanced research productivity (reviewed by Sambunjak et al., 2006).

Institutional innovation is also needed by research funders/donors (Fig. 3b). This must include the establishment of new criteria for awarding research funding that include measures of stakeholder engagement, and the provision of dedicated funding to solely support stakeholder engagement activities (Shanley and López, 2009). Doing so would place a greater emphasis on having end-users engaged in the science and provide research teams with funds to employ dedicated and skilled individuals to support engagement activities. Progress in this regard is been made, with numerous marine funding bodies globally requiring outreach and extension plans at the time of grant submission. For example in Kenya, the Western Indian Ocean Marine Science Association research grant program requires that all information be made accessible to practitioners through a range of activities including seminars, workshops and the development of targeted policy briefs, which can be budgeted in the research proposal. However, research funders must also monitor and evaluate knowledge exchange activities throughout the projects durations to place increased accountability on both scientists and their organisations to undertake knowledge exchange activities to an appropriate standard. Research funders and donors could also fund the development of systematic reviews through a similar model to the Cochrane Collaboration, to complement alternate efforts to improve knowledge exchange.

Finally, to enhance knowledge exchange among marine scientists and decision-makers institutional innovation is also needed by decision-making agencies (Fig. 3c). Specifically, marine decision-makers at both the individual and institutional level must make a

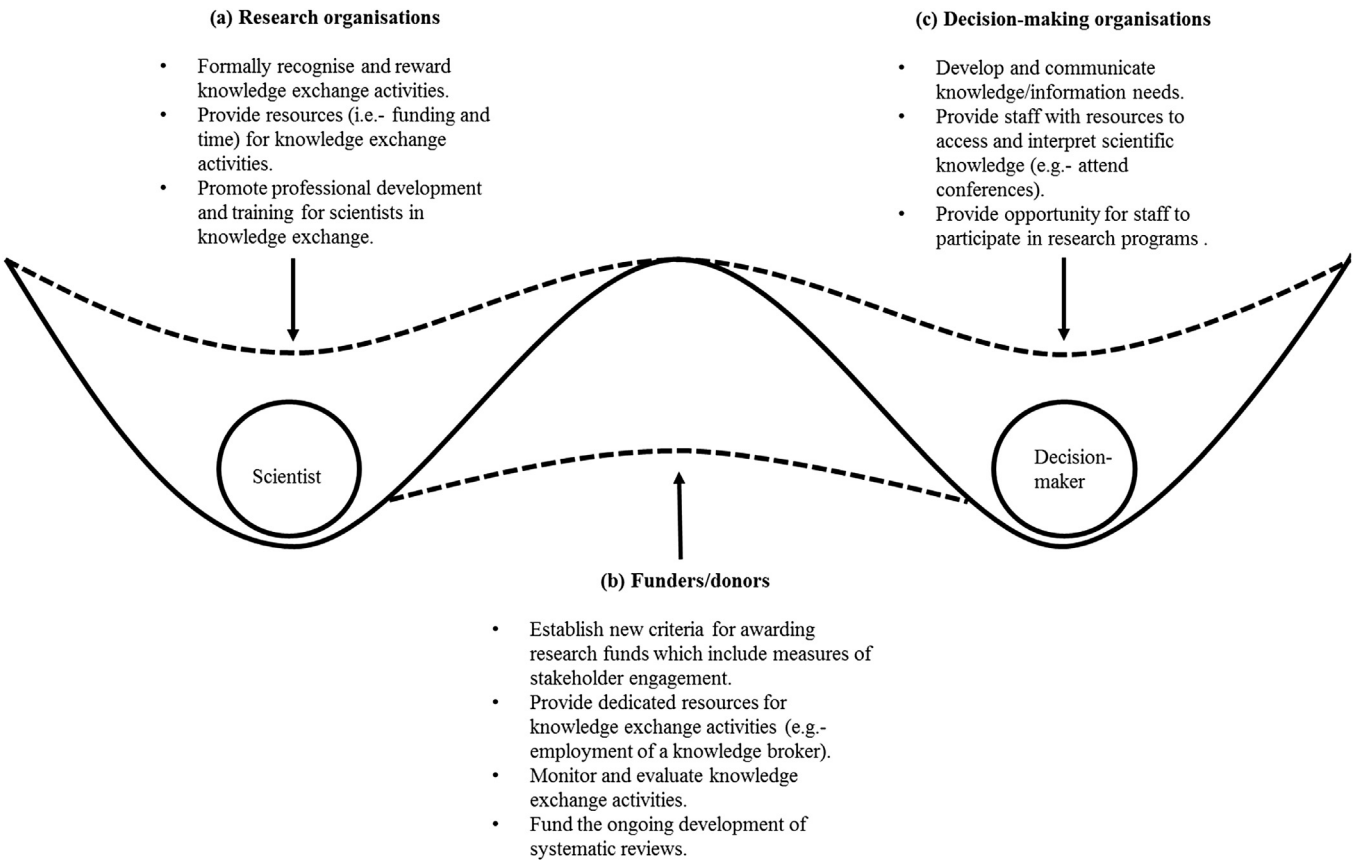

Fig. 3. A conceptual diagram illustrating the ways in which knowledge exchange among marine scientists and decision-makers can be enhanced through a range of institutional innovations. This representation is based on resilience thinking (Gunderson and Holling, 2002; Walker and Salt, 2006), in which stability is represented by the pits containing the scientist and decision maker balls, and the peak between these stable (but undesirable states) represents the barriers. Accordingly, the solid lines represent a state with poor knowledge exchange among scientists and decision-makers, while the dashed lines represents a state where institutional innovations are adopted enabling greater interaction and knowledge exchange between all parties.

concerted effort to move beyond their typical focus on day-to-day operation, to allow long-term strategic reflection on future research and development priorities (Roux et al., 2006). Resources must then be available to communicate these priorities to scientists to help guide the development of future funding and research proposals. Similarly, decision-making agencies must provide their staff with the flexibility and resources to participate in knowledge exchange activities (Lachapelle et al., 2003), such as participating in research projects to enable knowledge co-production and/or attending scientific conferences to help individual decision-makers stay abreast of the most current scientific literature. To aid this, decision-making agencies must establish a clear mandate in relation to natural resource management goals and objectives to enable and empower their staff to pursue this mandate and take action (Jantarasami et al., 2010).

5. Future research to improve knowledge exchange among marine scientists and decision-makers

Despite the documented increase in effort to improve knowledge exchange among marine scientists and decision-makers in recent times, an implementation gap remains, thus continuing to undermine the adaptive governance of marine resources. This is not particularly surprisingly given that our understanding of knowledge exchange is in its infancy, with many aspects remaining poorly understood within the environmental sector (Fazey et al., 2013). For example, the literature on knowledge exchange has largely portrayed knowledge exchange as a tool rather than a complex and dynamic process with multiple interpretations and uncertainties (Fazey et al., 2013). As such, while theoretical frameworks such as knowledge co-production or boundary organisations provide a potentially suitable mechanism for improving knowledge flow, they do not address the key underlying causes impeding knowledge exchange (i.e – cultural differences), nor do they provide insight into how knowledge exchange operates under different contexts or the individual skills needed to facilitate knowledge exchange. We suggest that several critical knowledge gaps must be filled in order to enhance knowledge exchange among marine scientists and decision-makers.

Firstly, the vast majority of studies to date in relation to knowledge exchange have been based largely on qualitative and theoretically-oriented evidence. Thus while a conceptual understanding of knowledge exchange has being developed, there is a distinct lack of quantitative empirical evidence to support these claims and guide future knowledge exchange activities (described by Reed et al., 2014). Filling this gap and developing an empirical understanding of knowledge exchange is crucial for understanding the full extent of the problem, determining the relative importance of potential barriers, and thus developing and implementing the most appropriate strategies to improve knowledge exchange.

Furthermore, most literature to date on knowledge exchange between scientists and decision-makers in relation to marine resource management has been based on case studies in single locations, primarily from developed nations within clearly defined

governance structures for the resource sectors. The results of these studies are unlikely to be representative of other geographic locations, particularly in developing nations, where governance structures are less clearly defined and access to scientific information is more limited (Evans et al., 2011; Bennett and Dearden, 2014). It is likely that the relative importance of barriers to knowledge exchange, and thus the strategies for overcoming identified barriers, will vary between geographic regions. There remains a need, therefore, to conduct studies at different geographic and governance scales on knowledge exchange to understand how the relationship between science and decision-making varies amongst different locations and under different conditions. This may be achieved via projects such as the Millennium Ecosystem Assessment, which considered local consequences of ecosystem change on human well-being and the scientific basis for action needed to enhance the sustainable use of those systems, thus having implications for knowledge exchange over broader scales (MEA, 2005).

Describing the traits that influence the effectiveness and efficiency of knowledge exchange activities requires attention (Dobbins et al., 2009). As defined by Fazey et al. (2013), in this context *effectiveness* relates to the extent to which the desired outcomes of a knowledge exchange process matches the actual observed outcomes, while *efficiency* refers to how easily an outcome is achieved given a specific set of resources such as time or funding. Accordingly, while two different approaches to knowledge exchange might produce similar outcomes (i.e. – similar effectiveness), they may differ significantly in the resources they require to achieve this outcome, therefore rendering one process more efficient (Laycock et al., 2011). The success of any approach for improving knowledge exchange (e.g. – knowledge co-production, knowledge brokers, boundary organisations, etc; Fig. 2), will be dependent on the desired outcomes and a range of contextual factors such as the resources available and the individual worldviews of participants (e.g. Entwistle and Smith, 2002). Further research will be critical for elucidating the key traits influencing effectiveness and efficiency, so as to identify the best knowledge exchange approach for a given activity.

Central to the idea of measuring the effectiveness of knowledge exchange activities is the ability to evaluate knowledge exchange activities (Bellamy et al., 2001; Fazey et al., 2013). However, very few projects have evaluated and documented the outcomes of knowledge exchange processes (but see Meagher et al., 2008; Phillipson et al., 2012; Fazey et al., 2014). Evaluation is particularly challenging in relation to knowledge exchange activities, given that successful outcomes are difficult to define and thus measure (Fazey et al., 2013). Examples of measurements may include metrics such as the "recency" or number of scientific articles used in management plans, or co-led research projects on topics of policy relevance. Evaluation will be critical for ensuring that knowledge exchange processes can respond flexibly to new insights so that they may achieve more effective results. In turn, such evaluations are also needed to ensure that practical and innovative solutions to management challenges can be developed and implemented to support adaptive governance arrangements (Connick and Innes, 2003; Pahl-Wostl, 2009).

Methods to evaluate knowledge exchange activities are urgently needed, and must also be routinely embedded in interdisciplinary and multi-stakeholder research (Fazey et al., 2014; Reed et al., 2014). Quantitative research approaches will be central to achieving this, in that they can be used to determine and articulate clearly defined outcomes associated with knowledge exchange activities (i.e – typology of success), and monitor and evaluative the success of activities against the desired outcomes. For example, as described in the previous section a growing body of literature has identified the potential of using knowledge brokers to improve knowledge exchange between scientists and decision-makers. A key trait underpinning the success of knowledge brokers is the extent to which they can form extensive social networks, both internal and external to their organisation, over time and connect people within their networks to facilitate knowledge flow (Crona and Bodin, 2006; Crona and Parker, 2012). Methods such as social network analysis (SNA) that track network growth and evaluate the strength of relationships over both spatial and temporal scales can therefore be used to monitor and evaluative the effectiveness of knowledge brokers (Borgatti and Halgin, 2011; Prell, 2012). Additional research is needed to understand the viability of using tools such as SNA for this purpose, and how this information could then be used to inform and improve future knowledge brokering strategies. Similarly, the implementation of stakeholder surveys throughout the duration of a research project can provide information regarding the extent to which knowledge exchange has successfully occurred, and identify areas and options for future improvement. Quantitative survey tools such as Likert scale assessments could be used in this regard, in that they allow perceptions of different stakeholders to be tracked over time (i.e – throughout the research project) in a cost-effective manner that is not onerous on either the research team or their stakeholders (Bryman, 2012). Further research into the viability of using such tools is therefore also needed.

Further research is needed to determine the specific expertise and skills required by individuals to support and facilitate successful knowledge exchange activities. This would allow training and development programs to be designed and tailored for maximum benefit to participants. This would be particularly beneficial for early career marine scientists, who acknowledge that a lack of skills and expertise in relation to knowledge exchange activities prevented them from engaging with environmental decision-makers (Cvitanovic et al., 2015). Longitudinal studies could then be used to track the experience and outcomes for different approaches, so as to refine training and development programs for maximum benefit.

Finally, further research is also needed to understand how new and evolving social media (e.g – Twitter) and web based platforms (e.g – ResearchGate) can better support knowledge exchange among scientists and decision-makers. The rise of such media has provided new opportunities for communication, networking and idea sharing (Thaler et al., 2012; Darling et al., 2013), and such technologies are already been used to share knowledge among diverse groups of stakeholders (e.g. Ogden, 2013). For marine scientists in particular, social media is likely to represent an effective means of communication, given the inherent charismatic nature of marine species and systems. An evaluation of the ways in which social media and web-based platforms can add value to knowledge exchange processes, therefore, may help scientists to better utilise such technologies.

6. Conclusion

Adaptive governance structures promoting collaborative, flexible and learning based approaches to management are needed to effectively manage marine resources and the services they provide to society (Österblom and Folke, 2013). Achieving this goal requires improved knowledge exchange among scientists and decisions-makers. In this paper we have shown how several significant and ongoing barriers to knowledge exchange persist, undermining efforts to sustainably and efficiently manage these resources. We have also outlined a range of options for overcoming these barriers, and the enabling conditions for their implementation. A resilience conceptualisation that highlights strategies for improved knowledge exchange may be a useful explanatory tool. While the

innovations needed are large in scale and potentially costly, doing so will inevitably improve the governance of marine resources globally, ensuring their long-term persistence and the livelihoods of the millions of people worldwide that depend upon them.

Acknowledgements

We thank M. Howden, C. James, K. Waples and K. Cvitanovic for insightful discussions that led to the development of, and greatly improved, this manuscript. We also thank the two anonymous reviewers for their constructive comments and suggestions on an earlier version of this manuscript. Funding was provided by CSIROs Climate Adaptation Flagship.

References

Acheson, J.M., 2006. Institutional failure in resource management. Annu. Rev. Anthropol. 35, 117–134.
Addison, P.F.E., Flander, L.B., Cook, C.N., 2015. Are we missing the boat? current uses of long-term biological monitoring data in the evaluation and management of marine protected areas. J. Environ. Manage. 149, 148–156.
Aswani, S., Hamilton, R.J., 2004. Integrating indigenous ecological knowledge and customary sea-tenure with marine and social science for conservation of bumphead parrotfish (*Bolbometapon muricatum*) in the Roviana Lagoon, Solomon Islands. Environ. Conserv. 31, 69–83.
Beger, M., Babcock, R., Booth, D.J., Bucher, D., Condie, S.A., Creese, B., Cvitanovic, C., Dalton, S.J., Harrison, P., Hoey, A., Jordan, A., Loder, J., Malcolm, H., Purcell, S.W., Roelfsema, C., Sachs, P., Smith, S.D.A., Sommer, B., Stuart-Smith, R., Thomson, D., Wallace, C.C., Zann, M., Pandolfi, J.M., 2011. Research challenges to improve the management and conservation of subtropical reefs to tackle climate change threats. Ecol. Manage. Restor. 12 (2), e7–e10.
Bellamy, J.A., Walker, D.H., McDonald, G.T., Syme, G.J., 2001. A systems approach to the evaluation of natural resource management initiatives. J. Environ. Manage. 63, 407–423.
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.
Bensaude-Vincent, B., 2009. A historical perspective on science and its "others". Isis 100, 359–368.
Berkes, F., Folke, C., 1998. Linking Social and Ecological Systems, Management Practices and Social Mechanisms for Building Resilience. Cambridge University Press, Cambridge, UK.
Berkes, F., 2009. Evolution of co-management: role of knowledge generation, bridging organizations and social learning. J. Environ. Manage. 90, 1692–1702.
Berkes, F., Colding, J., Folke, F. (Eds.), 2003. Navigating Social–ecological Systems Building Resilience for Complexity and Change. Cambridge University Press Cambridge, UK.
Best, A., Holmes, B., 2010. Systems thinking, knowledge and action: towards better models and methods. Evid. Policy 6, 145–159.
Borgatti, S.P., Halgin, D.S., 2011. On network theory. Organ. Sci. 22, 1168–1181.
Briggs, S.V., 2006. Integrating policy and science in natural resources: why so difficult? Ecol. Manage. Restor. 7, 37–39.
Brown, R.R., Farrelly, M.A., 2009. Delivering sustainable urban water management: a review of the hurdles we face. Water Sci. Technol. 59, 839–846.
Bryman, A., 2012. Social Research Methods. Oxford University Press, Oxford.
Butler, L., 2008. Using a balanced approach to bibliometrics: quantitative performance measure in the Australian research quality framework. Ethics Sci. Environ. Polit. 8, 83–92.
Cash, D.W., Moser, S.C., 2000. Linking global and local scales: designing dynamic assessment and management processes. Glob. Environ. Change 10, 109–120.
Cash, D.W., Clark, W.C., Alcock, F., Dickson, N.M., Eckley, N., Guston, D.H., Jager, J., Mitchell, R.B., 2003. Knowledge systems for sustainable development. Proc. Natl. Acad. Sci. 100, 8086–8091.
Cash, D., Buizer, J., 2005. Knowledge-action Systems for Seasonal to Interannual Climate Forecasting: Summary of a Workshop. The National Academies Press, Washington, DC, USA.
Ceccarelli, D.M., Richards, Z.T., Pratchett, M.S., Cvitanovic, C., 2011. Rapid increase in coral cover on an isolated coral reef, the Ashmore Reef national nature reserve, north-western Australia. Mar. Freshw. Res. 62, 1214–1220.
Chaffin, B.C., Gosnell, H., Cosens, B.A., 2014. A decade of adaptive governance scholarship: synthesis and future directions. Ecol. Soc. 19 (3), 56.
Clarke, B., Stocker, L., Coffey, B., Leith, P., Harvey, N., Baldwin, C., Baxter, T., Bruekers, G., Galano, C.D., Good, M., Haward, M., Hofmeester, C., de Freitas, D.M., Mumford, T., Nursey-Bray, M., Kriwoken, L., Shaw, J., Shaw, J., Smith, T., Thomsen, D., Wood, D., Cannard, T., 2013. Enhacning the knowledge-governance interface: coasts climate and collaboration. Ocean Coast. Manage. 86, 88–99.
Connick, S., Innes, J.E., 2003. Outcomes of collaborative water policy making: applying complexity thinking to evaluation. J. Environ. Plan. Manage. 46, 177–197.
Contandriopoulos, D., Lemire, M., Denis, J.L., Tremblay, É., 2010. Knowledge exchange processes in organizations and policy arenas: a narrative systematic review of the literature. Milbank Q. 88, 444–483.
Cook, C.N., Hockings, M., Carter, R.W., 2010. Conservation in the dark? the information used to support management decisions. Front. Ecol. Environ. 8, 181–186.
Cook, C.N., Carter, R.W., Fuller, R.A., Hockings, M., 2012. Managers consider multiple lines of evidence important for biodiversity management decisions. J. Environ. Manage. 113, 341–346.
Cook, C.N., Mascia, M.B., Schwartz, M.W., Possingham, H.P., Fuller, R.A., 2013a. Achieving conservation science the bridges the knowledge-action boundary. Conserv. Biol. 27, 669–678.
Cook, C.N., Possingham, H.P., Fuller, R.A., 2013b. Contribution of systematic reviews to management decisions. Conserv. Biol. 27, 902–915.
Cornell, S., Berkhout, F., Tuinstra, W., Tàbara, J.D., Jäger, J., Chabay, I., de Wit, B., Langlais, R., Mills, D., Moll, P., Otto, I.M., Petersen, A., Pohl, C., van Kerkhoff, L., 2013. Opening up knowledge systems for better responses to global environmental change. Environ. Sci. Policy 28, 60–70.
Cortner, H.J., 2000. Making science relevant to environmental policy. Environ. Sci. Policy 3, 21–30.
Crona, B.I., Bodin, O., 2006. What you know is who you know? communication patterns among resources extractors as a prerequisite for co-management. Ecol. Soc. 11, 7.
Crona, B.I., Parker, J.N., 2012. Learning is support of governance: theories, methods and a framework to assess how bridging organisations contribute to adaptive resource governance. Ecol. Soc. 17, 32.
Cullen, P., 1990. The turbulent boundary between water science and water management. Freshw. Biol. 24, 201–209.
Cvitanovic, C., Wilson, S.K., Fulton, C.J., Almany, G.R., Anderson, P., Babcock, R.C., Ban, N.C., Beedon, R., Beger, M., Cinner, J., Dobbs, K., Evans, L.S., Farnham, A., Friedman, K., Gale, K., Gladstone, W., Grafton, Q., Graham, N.A.J., Gudge, S., Harrison, P., Holmes, T.H., Johnstone, N., Jones, G.P., Jordan, A., Kendrick, A., Klein, C.J., Little, L.R., Malcolm, H., Morris, D., Possingham, H.P., Prescott, J., Pressey, R.L., Skilleter, G.A., Simpson, C., Waples, K., Wilson, D., Williamson, D.H., 2013. Critical research needs for managing coral reef marine protected areas: perspectives of academics and managers. J. Environ. Manage. 114, 84–91.
Cvitanovic, C., Fulton, C.J., Wilson, S.K., van Kerkhoff, L., Cripps, I.L., Muthiga, N., 2014a. Utility of primary scientific literature to environmental managers: an international case study on coral-dominated marine protected areas. Ocean Coast. Manage. 102, 72–78.
Cvitanovic, C., Marshall, N.A., Wilson, S.K., Dobbs, K., Hobday, A.J., 2014b. Perceptions of Australian marine protected area managers regarding the role, importance, and achievability of adaptation for managing the risks of climate change. Ecol. Soc. 19 (4), 33.
Cvitanovic, C., Hobday, A.J., van Kerkhoff, L., Marshall, N.A., 2015. Overcoming barriers to knowledge exchange for adaptive resource management; the perspectives of Australian marine scientists. Mar. Policy 52, 38–44.
Dale, A., Armitage, D., 2011. Marine mammal co-management in Canada's Arctic: knowledge co-production for learning and adaptive capacity. Mar. Policy 35, 440–449.
Darling, E.S., Shiffman, D., Côté, I.M., Drew, J.A., 2013. The Role of Twitter in the Life Cycle of a Scientific Publication. PeerJ PrePrints, 1:e16v1.
Deelstra, Y., Nooteboom, S.G., Kohlmann, H.R., van den Berg, J., Innanen, S., 2003. Using knowledge for decision-making purpose in the context of large projects in the Netherlands. Environ. Impact Assess. Rev. 23, 517–541.
Dessler, D., 1999. Constructivism within a positivist social science. Rev. Int. Stud. 25, 123–127.
de Jonge, V.N., Pinto, R., Turner, R.K., 2012. Integrating ecological, economic and social aspects to generate useful management information under the EU Directives' 'ecosystem approach'. Ocean Coast. Manage. 68, 169–188.
de Jonge, V.N., Giebels, D., 2015. Handling the 'environmental knowledge paradox' in estuarine and coastal policy making. Ocean Coast. Manage. 108, 3–12.
Dobbins, M., Robeson, P., Ciliska, D., Hanna, S., Cameron, R., O'Mara, L., DeCorby, K., Mercer, S., 2009. A description of a knowledge broker role implemented as part of a randomized controlled trial evaluating three knowledge translation strategies. Implement. Sci. 4, 23.
Dovers, S., 2001. Institutional barriers and opportunities: processes and arrangements for natural resource management in Australia. Water Sci. Technol. 43, 215–226.
Dowd, A.M., Marshall, N., Fleming, A., Jakku, E., Gaillard, E., Howden, M., 2014. The role of networks in transforming Australian agriculture. Nat. Clim. Change 4, 558–563.
Endter-Wada, J., Blahna, D., Krannich, R., Bruson, M., 1998. A framework for understanding social science contributions to ecosystem management. Ecol. Appl. 8, 891–904.
Entwistle, N., Smith, C., 2002. Personal understanding and target understanding: mapping influences on the outcomes of learning. Br. J. Educ. Psychol. 72, 321–342.
Evans, L.S., Brown, K., Allison, E.H., 2011. Factors influencing adaptive marine governance in a developing country context: a cast study of Southern Kenya. Ecol. Soc. 16 (2), 21.
Evely, A.C., Pinard, M., Reed, M.S., Fazey, I., 2011. High levels of participation in conservation projects enhance learning. Conserv. Lett. 4, 116–126.
Fazey, I., Salisbury, J.G., Lindenmayer, D.B., Maindonald, J., Douglas, R., 2004. Can methods applied in medicine be used to summarise and disseminate conservation research? Environ. Conserv. 31, 190–198.

Fazey, I., Fischer, J., Lindenmayer, D.B., 2005. What do conservation biologist publish? Biol. Conserv. 124, 63–73.
Fazey, I., Fazey, J.A., Salisbury, J.G., Lindenmayer, D.B., Dovers, S., 2006. The nature and role of experiential knowledge for environmental conservation. Environ. Conserv. 33, 1–10.
Fazey, I., Evely, A.C., Reed, M.S., Stringer, L.C., Kruijsen, J., White, P.V.L., Newsham, A., Jin, L., Cortazzi, M., Phillipson, J., Blackstock, Entwistle, N., Sheate, W., Armstrong, F., Blackmore, C., Fazey, J., Ingram, J., Gregson, J., Lowe, P., Morton, S., Trevitt, C., 2013. Knowledge exchange: a review and research agenda for environmental management. Environ. Conserv. 40, 19–36.
Fazey, I., Bunse, L., Msika, J., Pinke, M., Preedy, K., Evely, A.C., Lambert, E., Hastings, E., Morris, S., Reed, M.S., 2014. Evaluating knowledge exchange in interdisciplinary and multi-stakeholder research. Glob. Environ. Change 25, 204–220.
Fulton, E.A., Boschetti, F., Sporcic, M., Jones, T., Little, L.R., Dambacher, J.M., Gray, R., Scott, R., Gorton, R., 2015. A multi-model approach to engaging stakeholder and modellers in complex environmental problems. Environ. Sci. Policy 48, 44–56.
Glass, J.R., Kruse, G.H., Miller, S.A., 2015. Socioeconomic considerations of the commercial weathervane scallop fishery off Alaska using SWOT analysis. Ocean Coast. Manage. 105, 154–165.
Grorud-Colvert, K., Lester, S.E., Airame, S., Neeley, E., Gaines, S.D., 2010. Communicating marine reserve science to diverse audiences. Proc. Natl. Acad. Sci. U. S. A. 107, 18306–18311.
Gunderson, L., Holling, C.S., 2002. Panarchy: understanding transformations in human and natural systems. Island Press.
Guston, D.H., 2001. Boundary organizations in environmental policy and science: an introduction. Sci. Technol. Hum. Values 26, 339–408.
Hallegatte, S., 2009. Strategies to adapt to an uncertain climate change. Glob. Environ. Change 19, 240–247.
Higgins, J.P.T., Green, S. (Eds.), 2008. Cochrane handbook for Systematic Reviews of Interventions: Cochrane Book Series. The Cochrane Collaboration and John Wiley and sons Ltd, England, UK.
Hoey, A.S., Pratchett, M.S., Cvitanovic, C., 2011. High macroalgal cover and low coral recruitment undermines the potential resilience of the world's southernmost coral reef assemblages. PLoS One 6 (10), e25824.
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. 20 (7), 380–386.
Jacobson, N., Butterill, D., Goering, P., 2004. Organizational factors that influence university-based researchers' engagement in knowledge transfer activities. Sci. Commun. 25, 246–259.
Jantarasami, L.C., Lawler, J.J., Thomas, C.W., 2010. Institutional barriers to climate change adaptation in U.S. National Parks and Forests. Ecol. Soc. 15, 33.
Jordan, G., Maloney, W.A., 1997. Accounting for subgovernments – explaining the persistence of policy communities. Adm. Soc. 29, 557–583.
Kinzig, A.P., 2001. Bridging disciplinary divides to address environmental and intellectual challenges. Ecosystem 4, 709–715.
Kirchhoff, C., 2013. Understanding and enhancing climate information use in water management. Clim. Change 119, 495–509.
Knight, A.T., Cowling, R.M., Rouget, M., Balmford, A., Lombard, A.T., Campbell, B.M., 2008. Knowing but not doing: selecting priority conservation areas and the research-implementation gap. Conserv. Biol. 22 (3), 610–617.
Kukla, A., 2000. Social Constructivism and the Philosophy of Science. Routledge, London, UK.
Lacey, J., Howden, M., Cvitanovic, C., Dowd, A.M., 2015. Informed adaptation: ethical considerations for adaptation researchers and decision-makers. Glob. Environ. Change 32, 200–210.
Lachapelle, P.R., McCool, S.F., Patterson, M.E., 2003. Barriers to effective natural resource planning in a 'messy' world. Soc. Nat. Resour. 16, 473–490.
Laycock, H.F., Moran, D., Smart, J.C.R., Raffaelli, D., White, P., 2011. Evaluating the effectiveness and efficiency of biodiversity conservation spending. Ecol. Econ. 70, 1789–1796.
Leviston, Z., Walker, I., 2012. Beliefs and denials about climate change: an Australian Perspective. Ecopsychology 4, 277–285.
Linklater, W.L., 2003. Science and management in a conservation crisis: a case study with rhinoceros. Conserv. Biol. 17, 968–975.
Longino, H., 1990. Science as Social Knowledge. Princeton University Press, New Jersey.
MEA, 2005. Ecosystems and Human Well-Being. General synthesis. Millennium Ecosystem Assessment. Island Press, Chicago.
Mahon, R., McConney, P., Roy, R.N., 2008. Governing fisheries as complex adaptive systems. Mar. Policy 32, 104–112.
Majone, G., 1989. Evidence, Argument and Persuasion in the Policy Process. Yale University Press, New Haven.
Mascia, M.B., 2003. Conservation and the social sciences. Conserv. Biol. 17, 649–650.
McNie, E.C., 2007. Reconciling the supply of scientific information with user demands; an analysis of the problem and review of the literature. Environ. Sci. Policy 10, 17–38.
Meagher, L., Lyall, C., Nutley, S., 2008. Flows of knowledge, expertise and influence: a method for assessing policy and practice impacts from social science research. Res. Eval. 17, 163–173.
Meinke, H., Howden, S.M., Struik, P.C., Nelson, R., Rodriguez, D., Chapman, S.C., 2009. Adaptation science for agriculture and natural resource management-urgency and theoretical basis. Curr. Opin. Environ. Sustain. 1, 69–76.
Meyer, M., 2010. The rise of the knowledge broker. Sci. Commun. 32, 118–127.
Michaels, S., 2009. Matching knowledge brokering strategies to environmental policy problems and settings. Environ. Sci. Policy I2, 994–1011.
Millar, C.I., Stephenson, N.L., Stephens, S.L., 2007. Climate change and forests of the future: managing in the face of uncertainty. Ecol. Appl. 17, 2145–2151.
Mitton, C., Adair, C.E., McKenzie, E., Patten, S.B., Perry, B.W., 2007. Knowledge transfer and exchange: review and synthesis of the literature. Milbank Q. 85, 729–768.
Naess, L.O., 2013. The role of local knowledge in adaptation to climate change. WIREs Clim. Change 4, 99–106.
Nelson, R., Howden, M., Stafford-Smith, M., 2008. Using adaptive governance to rethink the way science supports Australian drought policy. Environ. Sci. Policy 11, 588–601.
Norton, B.C., 1998. Improving ecological communication: the role of ecologists in environmental policy formation. Ecol. Appl. 8, 350–364.
Ogden, L.E., 2013. Tags, blogs, tweets: social media as science tool? Bioscience 63, 148.
Ormerod, S.J., Barlow, N.D., Marshall, E.L.P., Kerby, G., 2002. The uptake of applied ecology. J. Appl. Ecol. 39, 1–7.
Osmond, D.L., Nadkarni, N.M., Driscoll, C.T., Andrews, E., Gold, A.J., Broussard Allred, S.R., Berkowitz, A.R., Klemens, M.W., Loecke, T.L., McGarry, M.A., Schwarz, K., Washington, M.L., Groffman, P.M., 2010. The role of interface organizations in science communication and understanding. Front. Ecol. Environ. 8, 306–313.
Österblom, H., Folke, C., 2013. Emergence of global adaptive governance for the stewardship of regional marine resources. Ecol. Soc. 18 (2), 4.
Pahl-Wostl, C., 2009. A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes. Glob. Environ. Change 19, 354–365.
Phillipson, J., Lowe, P., Proctor, A., Ruto, E., 2012. Stakeholder engagement and knowledge exchange in environmental research. J. Environ. Manage. 95, 56–65.
Pietri, D., McAfee, S., Mace, A., Knight, E., Rogers, L., Chornesky, E., 2011. Using science to inform controversial issues: a case study from the California ocean science trust. Coast. Manage. 39, 296–316.
Policansky, D., 1998. Science and decision-making for water resources. Ecol. Appl. 8, 610–618.
Prell, C., 2012. Social Network Analysis: History, Theory and Methodology. Sage Publications Ltd, London, UK.
Pullin, A.S., Knight, T.M., 2001. Effectiveness in conservation practice: pointers from medicine and public health. Conserv. Biol. 15, 50–54.
Raymond, C.M., Fazey, I., Reed, M.S., Stringer, L.C., Robinson, G.M., Evely, A.C., 2010. Integrating local and scientific knowledge for environmental management. J. Environ. Manage. 91, 1766–1777.
Reed, M., 2008. Stakeholder participation for environmental management: a literature review. Biol. Conserv. 141, 2417–2431.
Reed, M.S., Stringer, L.C., Fazey, I., Evely, A.C., Kruijsen, J.H.J., 2014. Five principals for the practice of knowledge exchange in environmental management. J. Environ. Manage. 146, 337–345.
Rich, R.F., 1979. The pursuit of knowledge. Knowledge: creation, diffusion. Utilization 1, 6.
Roberts, P.D., Stewart, G.B., Pullin, A.S., 2006. Are review articles a reliable source of evidence to support conservation and environmental management? A comparison with medicine. Biol. Conserv. 132, 409–423.
Roux, D.J., Rogers, K.H., Biggs, H.C., Ashton, P.J., Sergeant, A., 2006. Bridging the science – management divide: moving from unidirectional knowledge transfer to knowledge interfacing and sharing. Ecol. Soc. 11, 4.
Russell, J.T., Greenhalgh, E., Byrne, E., McDonnell, J., 2008. Recognizing rhetoric in health care policy analysis. J. Health Serv. Res. Policy 13, 40–46.
Salick, J., Ross, N., 2009. Traditional peoples and climate change. Glob. Environ. Change 19, 137–139.
Sambunjak, D., Straus, S.E., Marušić, A., 2006. Mentoring in academic medicine: a systematic review. J. Am. Med. Assoc. 296, 1103–1115.
Scholz, J.T., Wang, C.L., 2006. Cooptation or transformation? local policy networks and federal regulatory enforcement. Am. J. Political Sci. 50, 81–97.
Shaw, J., Danese, C., Stocker, L., 2013. Spanning the boundary between climate science and coastal communities: opportunities and challenges. Ocean Coast. Manage. 86, 80–87.
Shanley, P., López, C., 2009. Out of the loop: why research rarely reaches policy makers and the public and what can be done. Biotropica 41 (5), 535–544.
Simpson, C.J., 2008. Marine Science Strategy. Western Australia. Department of Environment and Conservation, p. 32.
Spilsbury, M.J., Nasi, R., 2006. The interface of policy research and the policy development process: challenges posed to the forestry community. For. policy Econ. 8, 193–205.
Stocklmayer, S., 2013. Engagement with science: models of science communication. In: Gilbert, J.K., Stocklmayer, S. (Eds.), Communication and Engagement with Science and Technology. Issues and dilemmas. Routledge, New York.
Sutherland, W.J., Pullin, A.S., Dolman, P.M., Knight, T.M., 2004. The need for evidence-based conservation. Trends Ecol. Evol. 19 (6), 305–308.
Thaler, A.D., Zelnio, K.A., Freitag, A., MacPherson, R., Shiffman, D., Bi, H., Goldstein, M.C., McClain, C., 2012. Digital environmentalism: tools and strategies for the evolving online ecosystem. In: Gallagher, D. (Ed.), Environmental Leadership: A Reference Handbook. SAGE Publications, London, England.
Turnbull, D., 1997. Reframing science and other local knowledge traditions. Futures 29, 551–562.

Underwood, J.N., Wilson, S.K., Ludgerus, L., Evans, R.D., 2013. Integrating connectivity science and spatial conservation management of coral reefs in north-west Australia. J. Nat. Conserv. 21, 163–172.
Van der Molen, F., Puente-Rodriguez, D., Swart, A.A., van der Windt, H.J., 2015. The co-production of knowledge and policy in coastal governance: Integrating mussel fisheries and nature restoration. Ocean Coast. Manage. 106, 49–60.
Van Kerkhoff, L., Lebel, L., 2006. Linking knowledge and action for sustainable development. Annu. Rev. Environ. Resour. 31, 445–477.
Van Kerkhoff, L., Lebel, L., 2015. Coproductive capacities: rethinking science-governance relations in a diverse world. Ecol. Soc. 20 (1), 14.
Walker, B., Salt, D., 2006. Resilience Thinking: Sustaining Ecosystems and People in a Changing World. Island Press.
Wilson, S.K., Adjeroud, M., Bellwood, D.R., Berumen, M.L., Booth, D., Bozec, Y.M., Chabanet, P., Cheal, A., Cinner, J., Depczynski, M., Feary, D.A., Gagliano, M., Graham, N.A.J., Halford, A.R., Halpern, B.S., Harborne, A.R., Hoey, A.S., Holbrook, S.J., Jones, G.P., Kulbiki, M., Letourneur, Y., De Loma, T.L., McClanahan, T., McCormick, M.I., Meekan, M.G., Mumby, P.J., Munday, P.L., Öhman, M.C., Pratchett, M.S., Riegl, B., Sano, M., Schmitt, R.J., Syms, C., 2010. Crucial knowledge gaps in current understanding of climate change impacts on coral reef fishes. J. Exp. Biol. 213, 894–900.