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A conceptual model to improve links between science, policy and practice in coastal management

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A R T I C L E I N F O

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A B S T R A C T

The literature has identified significant barriers to sustainable management of coastal resources due to lack of integration between science, policy and practice. The social and biophysical sciences are an important information source but are often neglected in policy and practice. The literature has identified the science, policy practice gaps as significant barriers to sustainable management of coastal resources. However, there is lack of research specifically covering the interactions between the three domains. This paper aims to: a) review the literature to identify gaps and related factors or themes contributing to the science-policy-practice disconnect; and b) propose a conceptual integrated model to address those gaps and to increase the uptake of science into policy and practice in coastal systems. The results confirm that there are gaps in the two way-links between science and policy and practice. Most research (64%) is published in the science to policy area, 32% in the policy and practice area, and only four % of the research is published in the science-policy-practice area. Effective integration is inhibited by issues of knowledge, uncertainty, communication, political and cultural issues and institutions or rules and a clear mechanism for linking science, policy and practice is needed. Frameworks may help alleviate the problem but may not be holistic or flexible enough to facilitate interactions across science-policy-practice. There needs to be a clear mechanism for integrating science, policy and practice. To address this a conceptual model of the interactions between science and policy and practice is proposed. The model includes two-way connections between science-policy-practice, mediated by both internal and external factors including key drivers, facilitators, inhibitors and barriers. The model is applied to three case studies, namely: implementing international level blue carbon policy at a local level; an historical perspective on mangrove damage and restoration at an Australian state level; and an Australian example of long-term interactions between science, policy and practice, illustrating how multiple connections and interactions can occur as projects proceed.

1. Introduction

Information flows between science, policy and practice are necessary prerequisites for managing environmental systems [1,2]. Policy needs to be based on a wide discipline range from both the social and natural sciences, as well as acknowledging the importance of political systems [3]. Evidence-based policy – a policy that is informed by rigorous science – is becoming more prominent in public and scientific debate. However, in practice integrating science into policy and decision-making processes that involve various stakeholders, policy agendas, institutions, different knowledge systems and other issues remains a significant challenge [4,5].

In the application of scientific knowledge in the policy-making process, opportunities and barriers for science-policy interactions have been discussed in the general literature over a considerable period of time [1,2]. A wide range of disciplines in both the social and natural sciences provide data, findings and recommendations, and these have the potential to improve human-environment interactions. However, the lack of integration or gap between science, policy and practice is a persistent problem that hinders the resolution of environmental issues [1,2,6]. Successful integration is often also hindered by an inability to account for complexities of the policy making process and the importance of political systems and broader governance context [3].

Management of coastal systems, especially intertidal ones, is an area where establishing connections between science, policy and practice can be particularly challenging. It involves many stakeholders with

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differing and often conflicting priorities and values and different agencies that deal with separate components of the coastal zone [7,8]. It is further complicated by the expansion of population in these areas, that increases pressures on the natural environment; furthermore, problems such as sea level rise are emerging as a result of changing climatic conditions [9,10].

There has been considerable academic and political interest in identifying processes that might contribute to integration of various types of knowledge into policy- and decision-making. Guiding principles, frameworks and models have been developed to address different aspects of human-environment interactions at various scales of environmental governance. Some examined the sustainability of social-ecological systems [11], adaptation [12,13], structured decision making [14] and Integrated Coastal Zone Management (ICZM) [7,15,16]. Although integration of various types of knowledge forms an integral part of these frameworks, they generally do not show complex flows, drivers, facilitators or barriers affecting integration between the three domains. This indicates a need for a holistic and flexible approach to deal with the gaps or disconnects identified in the literature; a need that is addressed in this paper.

This paper proposes a conceptual model that would assist with bridging the gaps or connections and interactions between science-policy-practice. It is based on a combination of findings from the literature review and the interdisciplinary expertise of the authors over 20 years of personal experience of being involved in various coastal management projects in Australia. Close involvement in projects with effective connections between scientists, policy-makers and practitioners, and observation of projects failing to achieve this connection, triggered interest in this issue. This led to exploring the underlying factors accounting for gaps between science-policy-practice and identifying the lack of a framework or conceptual model depicting interactions between all three.

This paper has two aims. The first is to review the recent literature on science, policy and practice in the coastal management context to identify factors or themes related to lack of integration as well as considering frameworks and models. The second is to develop a conceptual model that links science-policy-practice in a way that includes key components and linkages, and which is relevant to the uptake of science into policy and practice.

The following sections describe the methods used for the review, including the generation of themes, assessment of frameworks and construction of the model. This is followed by the results and discussion sections. First, a quantitative description and discussion of the distribution of references by source of the search is provided. Second, the themes identified in the review are described and discussed. Third, a summary of selected frameworks is provided. Fourth, the model is introduced and applied to the three case studies. Finally, the conclusion summarises the main findings and their significance.

2. Methods

A literature search was conducted on the Web of Science and references were downloaded into Endnote files. As the area of interest covers both social and natural sciences searches were conducted on the social science and science Web of Science sites on 17 and 18 October 2017 and first saved separately. Referring to these searches we subsequently use the terms 'science' and 'social science'. The searches were at the general level for Science AND Policy; for Policy AND Practice and then for all three terms. These were combined and duplicates removed resulting in the 'general literature' set which was not restricted to coastal topics. To refine the searches to focus on coastal topics at the land-sea interface the results were sub-searched creating a more concise sub-set, using specific search terms. These were: env* OR estuar* OR coast* OR wetland OR salt* OR mangr* (in the title). This resulted in the more concise post 2008 'coastal literature' set used for the review.

The reviewing process was based on a traditional qualitative content analysis approach [17]. First, the abstract of each article was used to select the papers that were clearly relevant to science, policy and practice. Reading each selected paper, key words or concepts were identified and these were compiled into themes or used to identify frameworks. The themes identified the main issues which were the basis of the structure of the results and discussion.

Based on their diverse and interdisciplinary backgrounds, co-authors were invited to discuss the issues raised. This was important for developing an understanding of the complex interactions between science, policy and practice, bridging discipline boundaries. The draft review was circulated to co-authors requesting input as examples or as commentary. The information provided was used to develop a conceptual model. The working of the model was assessed with reference to three case studies: implementation of an international blue carbon policy at a local level; an historical perspective of policy science interactions in the context of mangrove restoration at an Australian state level and a local Australian example of a long-term interaction between science policy and practice in an intertidal wetland.

3. Results and discussion

3.1. Literature review: the numbers

The review confirms that there is a lack of integration in the science-policy-practice arena. In the complete 'general literature', including over 11000 pre-2008 references, it was clear that the science-policy connection was similarly represented in both the 'science' and 'social science' searches. However, the position was different in the policy-practice area with a preponderance of material in the 'social science' area and much less in the 'science' search (Table 1). There were relatively few references (2.9%) covering all of the science-policy-practice connections.

Of the total from both searches published in 2008 or later there were 4280 (39%) references in the 'general literature' and 181 references in the 'coastal literature'. The pattern was similar to the larger datasets with a preponderance of papers published on the policy-practice area in the 'general literature' and on the science-policy area in the 'coastal literature'. In both cases there was a small percentage of papers in the science-policy-practice area (Fig. 1).

The contrast between the relative percentages of papers in the 'general' and the 'coastal' literature (Table 1, Fig. 1) may be related to the nature of the topics covered. Much of the research in the 'general literature' focussed on policy-practice in health, medicine and education, where practical outcomes are particularly important, demonstrable and more rigorously regulated by policy. Exploring how those areas deal with the science and policy connection may strengthen policy-practice interactions and provide useful insights for coastal management but is beyond the scope of the present paper. The smaller proportion of research on policy-practice issues in the coastal literature (Fig. 1) may reflect the complexity of environmental issues and variety of stakeholders, outcomes and their monitoring.

3.2. Integrating science, policy and practice: the themes

The main themes identified in the review that characterised gaps or

Table 1
Summary of the 'general literature' search. Note: the search term Science AND Policy AND Practice are not included as they represented only 2.9% of the overall results.

Source of search: 'science 'or 'social science'	Search term: Science AND Policy N = 5417	Search term: Policy AND Practice N = 6490
% from 'science	48%	28%
% from 'social science'	52%	72%

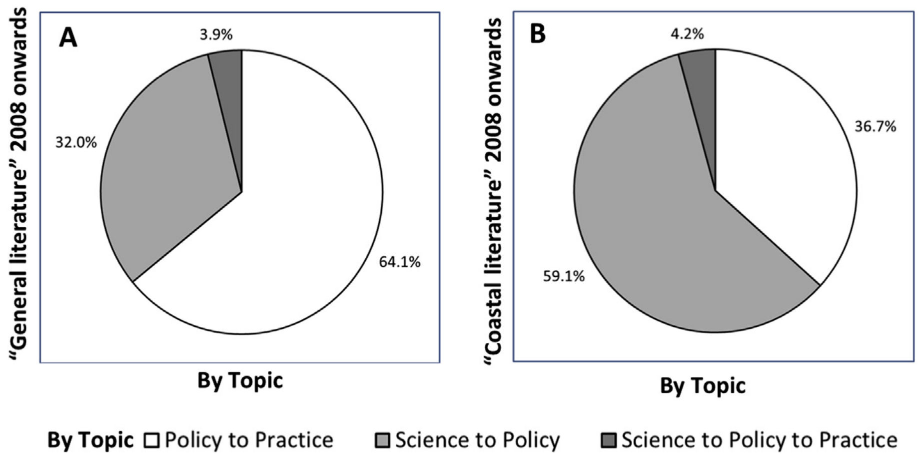

Fig. 1. Pie chart of papers published 2008 onwards in the science, policy and practice area. **A** is the 'general literature' set (n = 4280); **B** is the 'coastal literature 'set (n = 181).

lack of integration were knowledge, uncertainty, communication, political and cultural factors and institutions or rules. These will be examined in more detail in the following sections.

3.2.1. Knowledge

Knowledge that is relevant to policy is a basic requirement for good management. Lack or insufficiency of knowledge that inhibits policy- and decision-making is a recurring theme in the literature. Pullin et al. [18] referring to systematic reviews in environmental management published between 2006 and 2008, stated that knowledge gaps were 'a common finding'. This does not appear to have changed and many authors continue to refer to knowledge gaps [8,19–23]. These gaps are related to the lack of integration between knowledge areas, as the complexity of environmental issues requires multi- inter- and trans-disciplinary approaches to knowledge that cross conceptual and discipline boundaries [23–26].

There are many factors that contribute to knowledge gaps. Policy can be 'ahead of science', setting ambitious goals far beyond the scientific capacities to state how to achieve them in practice [27]. Even if information can be obtained, its application may face capacity constraints. Evaluation of impacts on ecosystems or their components, and monitoring and development of the knowledge base requires significant information processing capacity, resources, skills and expertise. In this context, insufficient funding and human resources have been acknowledged as key problems limiting the abilities of responsible authorities to acquire and apply environmental information [18,26]. Disjunct time scales can also exacerbate knowledge gaps. The time taken to create scientific knowledge is not consistent with the time requirements of policy-makers, for whom decisions may be urgent [1,28]. As an example, Snoeijs-Leijonmalma et al. [26] reported, for 16 Baltic Sea projects, that 70% of the research findings were published after the projects were completed.

Knowledge gaps can also be a result of the way information is produced. A mismatch between the broad questions framed by policy-makers and, sometimes, a narrow reductionist scientific approach is a common barrier for science uptake in policy [18]. Scientists may do small bite-sized research often focusing on theoretical issues so that research outcomes may be of little direct relevance to managers. Furthermore, environmental issues are often multi-scalar [21,29] and an issue and solution at one scale (e.g., national) may not be transferable to another scale (e.g., regional) [19]. 'Place-based' research or research at locally relevant scales has been noted as a potential solution [30]. Knowledge gaps may also be filled by structured literature reviews conducted by scientists for policy-making purposes, to garner as much information as possible and identify any gaps as issues for further research [18].

3.2.2. Uncertainty

Knowledge generated by science has an inherent uncertainty that is another issue in science-policy-practice integration. Uncertainty refers to a lack of confidence in the veracity of knowledge. Uncertainty is inherent in all scientific research. Quantitative research usually, but not always, uses a measure that shows a 5% chance of being wrong. That does not mean that it precludes actions. With a one in twenty chance of error, the question for policy-makers is whether that chance of error is acceptable and what would be the consequences of the knowledge being wrong (or how badly wrong?).

Most authors associated uncertainty with complexity [23,31–38]. However, there are many sources of uncertainty ranging from the facts and methods of science [39] to the uncertain interactions between various levels of management. The most comprehensive analysis of the uncertainty issue is provided by Maxim and van der Sluijs [20]. Their framework extends beyond substantive uncertainty, which is related to the content of knowledge, and includes contextual and production process dimensions in the areas of problem framing, knowledge production and its communication and use. In problem framing, these range from underlying uncertainties about, for example, assumptions and system boundaries, to uncertainties about expert knowledge and the relevance of community or local knowledge. Uncertainty can also be an issue in the interactions between policy actions and environmental outcomes [31] and in the overarching political system [2,10].

A concept often associated with uncertainty is the precautionary principle which states that 'where there is a threat of serious or irreversible damage lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation' [40]. This principle has been introduced in many regulatory frameworks worldwide and generally applied in environmental decision-making. Several authors refer to this principle [23,32,33,38]. The common themes addressed are: interpreting precaution when needing to proceed in the face of significant uncertainty; viewing precautionary and ecosystem approaches as complementary; needing adaptive management to incorporate new knowledge as it is generated, combining evidence with precaution. Accepting that there is uncertainty and applying the precautionary principle can have positive benefits, not only by reducing the risk of environmental harm but also by providing information on outcomes to inform further policy [23].

3.2.3. Communication

Even if knowledge and its uncertainty are addressed there remains the critical issue of communication. Effective communication is a process that is essential to bridge gaps between science and policy in order to enable best practice [21,41]. Communication may be written or articulated or may be informal, as in community participative activities.

Clear problem definition or problem framing is an underlying requirement for effective communication [23]. Clear framing, however, can be impeded by language differences between science and policy, in particular, by the use of discipline-specific jargon. A common language is necessary and the message needs to be relevant to the role of the recipient [1,42]. For example, scientists tend to use technical or discipline-specific language communicating uncertainties, whereas policy-makers prefer definite results [35]. Environmental science information has also been criticised for being contradictory, and this has enabled stakeholders with divergent positions in the policy-making process to selectively exclude material provided [43,44].

Some authors have proposed ways to minimise the communication problem. They note that a simple two-way interaction structure (conversation with) is more likely to improve communication than one-way methods (talking at) [1,19,21,36]. The language problem can be directly addressed by using translators or intermediaries to communicate between scientists and policy-makers (and practitioners) across knowledge boundaries [45]. Using user-targeted communication tools could include roles for linkers/brokers and facilitators [35]. Improved communication would also result from identifying factors that could lead to best practice [36]. One such evaluation for public servants concluded that mechanisms for effective communication included engaging with scientists, making critical information more easily available, and encouraging brainstorming to improve the integration between science and policy [31].

3.2.4. Politics and culture

Despite knowledge, uncertainty and communication being addressed, uptake of scientific knowledge can be hindered due to differing political agendas and cultural factors surrounding environmental problems. Many are related to stakeholder agendas: those of agencies, scientists, industry, NGOs and community. In some cases policy-makers may use information selectively and scientists may use information strategically, both to further particular agendas [20]. So called "cultural resistance" can emerge when the new knowledge is seen as incompatible with existing values, beliefs or experiences [41]. As discussed by Rayner [43], government agencies may develop "an anti-science culture" leading to resistance to knowledge uptake. This culture can emerge in response to what is termed "uncomfortable knowledge" that is, knowledge which, if accepted as valid, would have the capacity to undermine values and vested interests.

Several ways have been discussed to improve the integration of knowledge into policy- and decision-making processes. For example, Berkes [46] advocated co-management arrangements which present opportunities for developing knowledge partnerships between stakeholders thus enabling combination of different kinds of knowledge. Stewart et al. [41] suggested that knowledge exchange (dialogue and sharing) rather than knowledge transfer (unidirectional bridging gaps) would be a move towards reducing gaps. Other solutions include "boundary spanning" [5] or using "bridging organisations" in adaptive governance systems that have the capacity to strengthen effective governance by connecting (bridging) local actors and communities with other levels of management [47].

3.2.5. Institutions

Knowledge providers, policy-makers and managers are also guided by institutional contexts or systems of rules that define the scope of actions allowed to resolve policy problems. Rules or institutions are behavioural prescriptions that shape the patterns of social interactions and are the means through which societies achieve collective goals [48]. Although institutional frameworks have been identified as factors affecting knowledge integration [23,49], the institutional dimension often remains an overlooked factor.

A range of knowledge integration problems can be attributed to institutional factors. Mismatch of administrative and ecological boundaries and temporal scales of management are commonly mentioned institutional barriers. Jurisdictional boundaries that are not congruent with ecosystem boundaries, result in potentially inconsistent decisions by different agencies. This is especially an issue in coastal areas [32,50]. Operational level rules guiding interactions with environmental systems are often designed to specify objectives, the allowable scope of actions, enabling or constraining ecological conditions, or other guidance. The extent to which they make 'ecological sense' in relation to the environmental systems, or their properties under consideration, directly affects management outcomes. Institutional design also requires understanding of the information processing capacity, resources, skills and expertise of the governance actors and capacities of the governance system to appropriate the required resources (e.g., taxation, budgeting systems). Whether governance actors will be interested in pursuing environmental goals also depends on rules shaping incentives (e.g., penalties, enforcement, payments, compensations). Introduction of new values, such as ecosystem services, may require the design of new mechanisms and changes in current market exchange systems. Furthermore, rules may need to be altered to create incentives for management bodies to address cross-boundary effects, to co-operate or to share information or knowledge [51,52].

Both the scientific and political literature contain a variety of propositions for the design of management processes (e.g., Integrated Coastal Zone Management (ICZM), ecosystem-based management, adaptive management), which have important implications for institutional design. Proposed management frameworks, however, cannot always be fitted into the established regulatory systems. For example, while adaptive management has been widely advocated as an approach to address uncertainty, as several reviews suggest, there is a limited number of studies reporting implementation [53–55]. Various institutional constraints have been identified as barriers to implementation. For example, existing institutional frameworks have precluded ongoing adjustments in established land use rights and development approval processes [56,57] leaving 'no space' for corrective action [58]. Understanding the overarching institutional framework is thus another important factor that can contribute to improved applicability of scientific advice.

The next section provides a summary of a variety of frameworks and models that may be used to analyse the science-policy-practice interface.

3.3. Frameworks, models (and guidelines)

There is a variety of ways to improve the integration of science into policy and practice. The main methods are by means of frameworks, which are basic structures that underlie a system or concept and contain sets of variables. Papers that referred to frameworks in the title, abstract or text of the 'coastal literature' were selected for further analysis. They included applications of existing frameworks, presenting new ones and adding to existing ones. We further selected, as examples, references which offered new or amended frameworks relevant to the science-policy-practice theme. Twelve references have been selected and some key characteristics of the frameworks are shown in Table 2.

The diversity of frameworks and their variables reflect a broad range of issues considered in science-policy-practice integration. For the purposes of the review the frameworks have been classified as theoretical, conceptual and management. Theoretical frameworks offer new or application of existing theories that explain relations between the actors and the outcomes, whereas conceptual frameworks provide conceptual categories that can support the analysis of specific issues. Management frameworks include specific sets of steps, instructions and/or implementation guidelines.

All theoretical frameworks included in the review, address the knowledge production theme focusing on the shift from 'science-based' to 'participatory' or 'co-production' processes characterizing the science-policy and science-practice interfaces. For example, Carrozza [37] suggested that two theoretical frameworks – post normal science and

Table 2
Summary characteristics of framework references (in alphabetical order by author).

References	Topic and geographical focus	Type of framework	Science-policy-practice links	Format
Bremer & Glavovic 2013 [32]	Coastal management, New Zealand	Conceptual	Science-policy	Diagram & text
Bremer & Glavovic 2013 [19]	Coastal management	Theoretical	Science-policy	Text only
Brooks and Fairfull 2017 [49]	Coastal management, NSW, Australia	Theoretical	Policy-practice	Diagram, table & text
Carrozza 2015 [37]	Politics of science, climate change	Theoretical	Science-policy	Text only
Elliott et al., 2017 [60]	Marine management	Conceptual	Science-policy	Diagrams, tables & text
Keller 2010 [34]	Behaviour of science organisations	Theoretical	Science-policy	Text only
Maxim & van der Sluijs 2011 [20]	Uncertainty, quality of knowledge	Conceptual	Science-policy	Table & text
Nesshöver et al., 2017 [23]	Concept of nature-based solutions, Europe	Conceptual	Science-policy-practice	Diagram, tables & text
Pullin et al., 2009 [18]	Production of scientific knowledge for policy	Conceptual	Science-policy	Diagram and text
Runhaar 2015 [59]	Tools for integrating environmental objectives	Conceptual	Policy-practice	Table & text
Santos & Pierce 2015 [8]	Marine management, European Union	Management	Policy-practice	Diagrams, tables & text
Sarda et al., 2014 [61]	Marine management, focus on Canada and EU	Management	Policy-practice	Diagram, table & text

•DAPSI(W)R(M): Driver, Activities, Pressures, State changes, Impacts (on Welfare), Responses (as Measures).

co-production of knowledge – can be used to examine complex relationships between politics and science and the role of scientific advice in environmental policy. Similarly, in the context of integrated coastal management Bremer and Glavovic [19] noted the changes towards governance settings that enable inclusion of diverse forms of knowledge. They identified five key governance principles (ecosystem based, adaptive and precautionary, science based, interdisciplinary and participatory) for framing the science-policy interface. Keller [34] examined organisational behaviour theories that explain interactions between science assessment organisations and policy-makers, demonstrating that organisations employ strategies that can achieve both scientific credibility and political relevance.

Conceptual frameworks address a broader range of themes. The most comprehensive framework dealing with knowledge integration is that of Maxim and Van der Sluijs [20]. It includes a range of uncertainty variables that can affect knowledge quality during the whole knowledge process starting from problem framing to knowledge production and communication. The uncertainty issue is also addressed by Pullin et al. [18] who, drawing on health sciences, provided a framework for producting systematic reviews of available environmental knowledge. Brener and Glavovic [32] provided a conceptual framework to examine the shift from science-based to participatory approaches in the knowledge generation process. Other frameworks offer insights into a broader set of factors surrounding science-policy-practice integration. On the policy-practice side, Runhaar [59] examined a large variety of policy instruments that can be used to incorporate environmental objectives. His classification framework demonstrates a large variety of policy solutions that can be implemented depending on the governance mode (top-down, interactive, self-governance) and steering strategy employed (regulatory, economic, communication/information/analysis, organisation). Nesshöver et al. [23] clarified the concept of Nature Based Solutions (NBS), introduced in the policy area to promote nature as a way to solve environmental problems. Their process model places emphasis on multi- and trans-disciplinary knowledge required to operationalise NBS. Elliott et al. [60] have extended the familiar Driver-Pressure-State Impact-Response (DPSIR) framework to a DAPSI(W)R(M) to take a more holistic approach and to include human welfare. Similarly, they emphasised the engagement of a broad range of scientific disciplines to apply the framework for integrated marine management.

Management frameworks address the policy-practice interface. Most of the sources examined the implementation of ICZM and ecosystem-based management frameworks where the application of scientific and other knowledge is viewed as an integral part of the management cycle. For example, Sarda et al. [61] described ecosystem management for marine waters as based on three pillars – managerial, information and participatory – arranged on an adaptive trajectory towards achieving Good Environmental Status. In that framework the science input is linked to risk assessment and decision-making steps. Brooks and Fairfull [49] examined the implementation of an ICZM framework in New South Wales. Guided by the theory of 'inclusive development' and 'interactive governance', they demonstrated application of inclusive, consultative approaches capturing diverse sources of knowledge to identify benefits, assess risks and choose management options. They also noted that high level (third order) meta-governance has been identified as a key factor leading to successful implementation. Santos and Pierce [8] examined the scientific input required to implement the process of the Marine Strategy Framework Directive in Europe, noting the importance of funding and coordination in the knowledge generation process. They also identified the 'multi-level governance dynamics' as one of the biggest challenges for implementation.

In general, most of the frameworks reviewed were concerned with the science-policy connections with fewer in policy-practice. Connections between all three, were addressed in only one. This reflects the relative paucity of frameworks which address the whole knowledge production and application cycle or which identify factors contributing to the connections or gaps between science-policy-practice in the coastal zone. In the following section, this broad issue of how to portray the processes linking science-policy-practice is addressed by means of a conceptual model, based on the contributions of the co-authors and reflecting their diverse areas of interest.

3.4. The conceptual model

A way forward to attempt to bridge science-policy-practice gaps is to deal with all three in the one process, thereby keeping a common 'thread' of knowledge transfer throughout. A key aspect is the notion of coordination of knowledge across the science-policy-practice arenas. Does knowledge transition effectively from science to the other arenas? Is the meaning and intent retained? In a simple case, this may be established in the process of transfer and cooperative sharing, by collaboration. However, for more complex problems, this may not be sufficient, although still necessary. The idea of knowledge integration is often used to articulate this process but may be falling short. Integration of ideas into policy and practice may be the scientists' goals of transferring knowledge effectively and influencing policy and practice appropriately. However, because of differences in knowledge and its communication, experiences and skills, the policy or practice focus on the goal may obfuscate the science. Effective knowledge transfer, adoption and embedding into policy requires recognition that, for each, there are different relationships between science (derived knowledge) and policy and practice, and those differences need to be considered and accommodated.

In an attempt to bring the three together Fig. 2 is a conceptual diagram, developed and applied by the authors. It allows multiple and two-way interactions across each pair (science-policy-practice). The components of the model reflect the major issues identified in the review. For example, the two-way interactions are affected by external

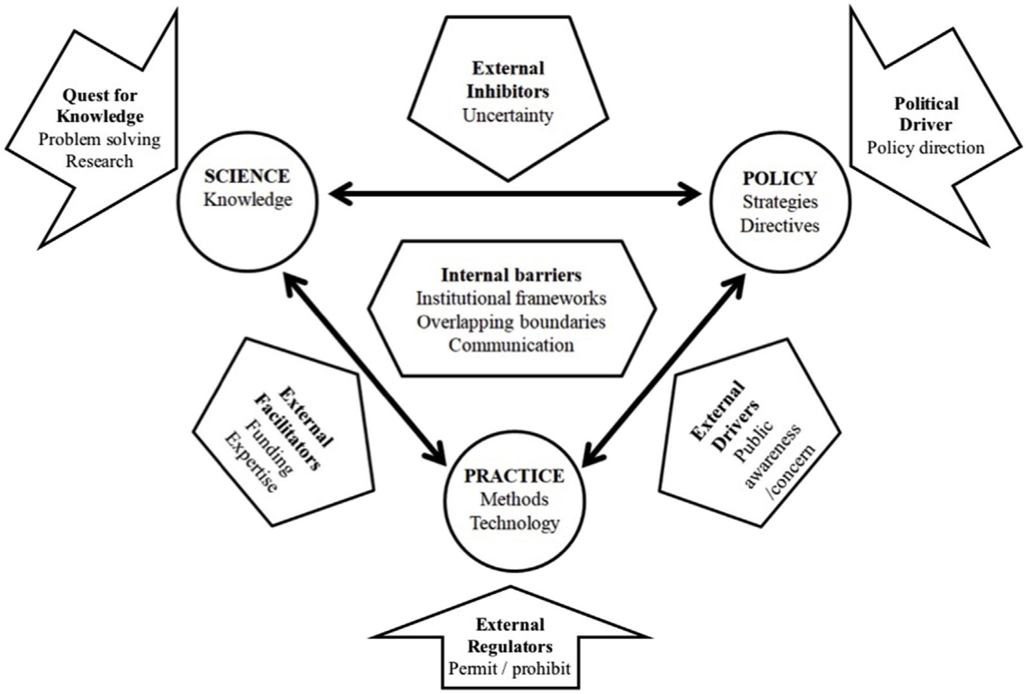

Fig. 2. A conceptual model bringing science, policy and practice together.

factors such as uncertainty, public awareness and funding and expertise. Science, policy and practice are driven respectively by the quest for knowledge, political directions and external regulators. Central to the system are the internal barriers including institutional frameworks, overlapping boundaries and communication. The model was applied to three case studies to illustrate its use, flexibility and potential to capture multiple interactions and illustrate how tracking the broader science-policy-practice connection can help improve understanding of the processes and lead to improved management outcomes.

3.5. Application of the model to case studies

Three case studies illustrate how the model in Fig. 2 works. Each illustrates this in different ways from an international to local level of governance. These were: applying international policy for blue carbon to local issues; an historical perspective on mangrove damage and restoration in New South Wales, Australia and an example of successful integration of science policy and practice in managing intertidal salt marshes. The approach below traces the processes of interactions between science policy and practice, highlighted by the use of capitals for the start of each part of the process and summarised as a continuous process at the end of each.

3.5.1. International policy for blue carbon applied to local issues

The Wylie et al. [62] review is a good illustration of applying high-level policy at local levels. The context was the important function of highly productive coastal blue carbon ecosystems in sequestering and storing carbon as well as providing other ecosystem services. Around one third of the global total blue carbon ecosystems have been lost over recent decades. As public and government awareness and concern has increased, international efforts have been made to address the loss of blue carbon ecosystems by including them in existing policy frameworks. Some of these involve carbon-financing mechanisms. For example, the United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UN-REDD) was launched in 2008 supporting REDD + processes to reduce emissions. Case studies from coastal ecosystems in Kenya, India, Vietnam and Madagascar were documented illustrating that high-level policy may not be relevant or applicable at the local level, where cultural or practical issues, limit its application [62]. Using the model in Fig. 2 we analyse the process.

SCIENCE: Science, in a problem-solving capacity, was the basis for the UN-REDD POLICY, which itself resulted from international awareness of the issue (external driver).

POLICY: Policy was intended to guide practice in the case studies.

PRACTICE: Practice was inhibited at the local level, by methodological constraints. Policy mechanisms were generally avoided due to the lengthy time required to fulfil the requirements and the cost involved at the local level. Both expertise and funding were issues (the absence of sufficient external facilitators).

SCIENCE: Scientific knowledge of the issue and the ecosystems, driven by the quest for knowledge, informed alternative practices which were adopted.

PRACTICE: The practices included different financial approaches or organic certification and mangrove restoration, which latter also met the aims of reducing carbon emissions.

To summarise: the process was SCIENCE to POLICY to PRACTICE then back to SCIENCE and on to revised PRACTICE.

3.5.2. An historical perspective on mangrove damage and restoration in New South Wales

As early as 1968 development activities were recognised as damaging mangroves in New South Wales [63]. The process illustrated in Fig. 2 is shown below.

SCIENCE: Based on science and the search for knowledge, some initial principles for estuary foreshore management were proposed in the late 1960s.

POLICY: As a result of public awareness (external driver) there was a government policy response in 1971 (appointment of a Minister for Environmental Control – a policy driver) and more detailed policy development [64].

PRACTICE: As a further response to public concern (external driver), mangrove restoration was considered and mangrove planting was carried out in the Parramatta River in the late 1970s and expanded into the mid 1980s with thousands of mangroves planted in the Hawkesbury River to compensate for the impacts of a gas pipeline river crossing [65].

SCIENCE: Scientific knowledge about restoration was enhanced by feedback from the practice.

POLICY: In 1983 New South Wales State Pollution Control Commission used scientific information to inform the preparation of a document outlining methods for transplanting mangroves. This could be considered a policy document as it was consistent with the then co-ordinating role of the State Pollution Control Commission under the Clean Waters Act 1970 of New South Wales.

SCIENCE: Uncertainty (external inhibitor) developed about planting as a response to mangrove loss with scientific research indicating that mangroves were encroaching onto saltmarsh and that saltmarshes could be threatened [66,67]. There were also community conflicts (external driver) over the desirability of mangrove restoration because of competition with other uses [68].

POLICY: A more integrated approach is being adopted and involves evidence-based management responses to reduce priority threats and risks that suppress the environmental, social, cultural and economic values of marine vegetation systems (i.e., mangrove and saltmarsh) [49].

To summarise: using the model in Fig. 2 SCIENCE alerted government that estuarine systems were threatened by un-regulated development leading to POLICY; POLICY was driven by public awareness and concern and led to PRACTICE and PRACTICE enhanced SCIENCE which led to improved POLICY in the 1983 practical guide. Then SCIENCE introduced uncertainty. Currently POLICY is being developed to reduce internal barriers and is an opportunity for progressing the integration between SCIENCE, POLICY and PRACTICE.

3.5.3. Successful integration of science-policy-practice in managing intertidal salt marshes

In Queensland, Australia, the aim was to develop a method of source reduction for disease vector mosquito control using environmental modification without adversely affecting ecosystem services [69]. The sequence is described below with reference to Fig. 2.

SCIENCE: The project began in 1980 starting with scientific research (driven by the quest for knowledge) into the ecosystem with a focus on environmental issues specifically related to mosquito life cycles. The research team included scientists, mosquito control personnel and government policy-makers, completing the connection between all three areas from the start of the project.

PRACTICE: In 1984 science informed technology, proposing a method that would interfere with the mosquito habitat requirements but not destroy the wetland. In 1985 technology facilitated the implementation of the project, and external regulators permitted it. The method was to construct runnels by hand [69] Runnels were shallow wide channels to increase tidal flushing, a practice that allowed fish access and inhibited mosquito larval survival. Science continued with regular monitoring in the field and by remote sensing leading to policy. Available funding and expertise (external facilitator) made this possible.

POLICY: In the early years the permit conditions (external regulation) informed policy in assessing applications to construct runnels (a strong link between practice and policy).

PRACTICE: By the late 1980s more projects were implemented and formal policy emerged under codes of practice: Fisheries Department Code of Practice in 1999, followed by a Mosquito Management Code of Practice in 2002. Technology further drove the system with feedbacks in the form of developing a runnel machine in 1992 with an improved version in 1994. This was to enable the expansion of the practice, following its demonstrated success.

SCIENCE: Scientific research continued over the time span of the project, facilitated by ongoing annual research funding. Impact assessments were carried out periodically and the 20-year assessment published in 2008 reduced uncertainty (an external inhibitor) indicating that the method incurred minimal risk of environmental harm [70]. The role of science was also to reassure the public and policy-makers (external drivers between policy and practice) that the method worked and did not compromise ecosystem values.

POLICY: The policies were updated and are still in operation both for construction and maintenance of runnels.

The link between science and policy and practice was strong and this was related to the fact that most of the people from the 1980s were still involved, albeit less directly, after 20 years.

To summarise: using the model in Fig. 2 SCIENCE led to PRACTICE solutions; PRACTICE (practical solutions) led to POLICY (codes); expanded PRACTICE led to improved PRACTICE (technology); continuing SCIENCE led to continuing POLICY support.

4. Conclusion

The review confirmed that there is a lack of integration between science, policy and practice that affects the achievement of environmental outcomes. The distribution of references showed that the largest percentage of references in the 'general literature' were concerned with aspects of policy-practice, whereas in the 'coastal literature' focus was more on the science-policy connection. This may be related to the complexity of coastal systems, the interdisciplinary nature of knowledge and multiple stakeholder values.

Several main themes emerged from the literature in the context of gaps or disconnections in the science-policy-practice area. They included: knowledge and its generation, uncertainty, communication, politics and culture that set a context for management and institutions that define allowable actions. There are frameworks that address different aspects of science, policy and practice integration in the context of coastal management. However, they rarely take a holistic approach and do not cover factors such as external drivers, facilitators, inhibitors or internal barriers.

The conceptual model proposed here provides a way to link science, policy and practice in two-way interactions, driven by the need for knowledge, political direction, regulation and mediated by external inputs or internal barriers. The three case studies demonstrated the application of the model in specific circumstances, with management outcomes. It showed that, at a general level, it is useful for analyzing the connections between science, policy and practice. It enables unique insights into the nature of each of the issues and may be used retrospectively as in case studies, or prospectively. Importantly, the model could also be used to assist management by identifying how management outcomes were inhibited or prevented and potentially finding the source of the problem, in particular where there are multiple feedback loops.

Other avenues for further research to address the shortfall of studies on policy-practice in the 'coastal literature' could include a review of this issue in the broader social science literature to explore the ways in which the policy-practice connections are made and the feasibility of adopting the methods used.

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