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Utility of primary scientific literature to environmental managers: An international case study on coral-dominated marine protected areas

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ABSTRACT

The integration of scientific information into the decision-making process for the management of marine resources remains a significant challenge, with the inaccessibility of primary scientific literature to environmental practitioners identified as a key limiting factor. Here, we quantify the use of primary scientific literature in environmental management plans, and explore potential barriers to the efficient integration of such scientific information into the decision-making process. Through a case study of coral dominated Marine Protected Areas (MPAs) spanning three countries (Australia, Kenya and Belize), we find that primary scientific literature represents only 14% of information cited in management plans. Such a low proportion is likely to be symptomatic of several issues regarding the accessibility of primary scientific literature to MPA managers, such as: 1. Long publication times for articles (average 40.2 ± 1.8 months); 2. Subscription-only access (up to 56% of articles behind paywalls); and/or 3. Poor articulation of management implications (only 19% of articles provided clear outcomes relevant to management). Such impediments can undermine the adaptive governance of MPAs, so we suggest improvements to knowledge transfer among scientists and managers via a diversity of approaches including knowledge brokers, boundary organisations, knowledge co-production and management-orientated summaries in research articles.

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1. Introduction

Integrating new information into decision-making processes associated with the management of natural resources is critical for adapting strategies according to new knowledge and evolving threats to ecosystem health and function (Berkes and Folke, 1998). While multiple sources of knowledge can inform the management of environmental resources (Cook et al., 2012), it is widely acknowledged that the incorporation of primary science into the decision-making process is critical for determining environmental baselines, improving our understanding of the likelihood and potential effects of natural and anthropogenic disturbances, and

predicting the implications of these changes for society (Sutherland et al. 2004). For example, the value of science in predicting the likely consequences of disturbances to environmental assets, and testing the effectiveness of possible management responses, is vital for allowing proactive rather than reactive management actions to be taken (Hockings, 2003; Hockings et al. 2009). Science also provides a robust and transparent evidence-base which reduces uncertainty and increases the likely success of conservation objectives being achieved (Sutherland et al. 2004).

Despite a dramatic increase in the number of applied scientific publications (Ormerod et al. 2002), an implementation gap between science and management action remains (Sutherland et al. 2004; Knight et al. 2008). Conservation managers often rely on individual experiences or other secondary sources of information in isolation from scientific evidence articulated in peer reviewed journal articles when developing and implementing conservation actions (Pullin et al. 2004; Cook et al. 2010). Such secondary sources

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of information can be problematic as it is difficult to tell whether the findings and their implications are based on the summation of a range of studies, from a well designed experiment, from experience in a single location, or simply subjective judgements based on the author's experiences (Sutherland et al. 2004). Accordingly, improving the uptake of primary science into the decision-making process should increase the likely success of management actions and strategies.

One of the most cited barriers to the successful integration of new scientific knowledge into management decisions is the inaccessibility of the primary scientific literature to environmental practitioners (Pullin and Knight, 2001, 2003). For example, it takes considerable time for results to be published following the completion of data collation (e.g. Kareiva et al. 2002; Fazey et al. 2005), and as such, information may be out of date and no longer useful to managers by the time it is available (Linklater, 2003). Even after results are published, the process of locating, accessing and reading primary literature can be too time consuming for environmental practitioners to undertake as part of their daily responsibilities (Pullin et al. 2004). This issue is exacerbated when articles are not readily available to decision-makers through open-access or agency journal subscriptions. Moreover, primary literature is often too technical for environmental managers to interpret and does not clearly articulate how the new results could assist management decisions (Fazey et al. 2005; Simonetti, 2011).

Understanding the extent to which each of these factors constrains the integration of science into management decisions is critical for developing mechanisms to facilitate improved uptake of science by environmental practitioners. Here, we aim to address this issue by assessing the extent to which primary science is currently used in management planning, and assess a range of potential barriers that may constrain the uptake of primary science by environmental practitioners in a marine context. While we acknowledge that scientific information can also enter the decision-making domain via other information sources such as commissioned technical reports, evaluating the role of these intermediary actors was beyond the scope of this study. Specifically, we aimed to quantify the: (1) time taken for scientific information to be available to end-users in published format; (2) proportion of scientific articles freely available to end-users; and (3) the clarity in which the conservation and management implications of a research article are articulated to end-users. Furthermore, given suggestions that a stronger emphasis should be placed on the systematic development of review papers to provide decision makers with digestible and accessible information (Pullin and Knight, 2001; Sutherland et al. 2004), we also quantify the extent to which review papers may assist in overcoming these barriers. In addressing these aims, we generated recommendations to overcome barriers relating to science accessibility, to promote more efficient uptake of science by environmental practitioners and allow the implementation of adaptive governance structures.

To answer the questions posed by this study we focus on coral-dominated Marine Protected Areas (MPAs) spanning three countries and oceanic regions (Pacific, Indian and Caribbean). In doing so, we build upon a recent study which found that managers of coral-dominated MPAs perceive there is less scientific literature available to inform their decisions on key issues than academic researchers working in the same regions (Cvitanovic et al. 2013). Given that MPAs are one of the primary conservation tools for managing coral reef resources, which support the livelihoods of over 500 million people globally (Moberg and Folke, 1999), it is critical we overcome any barriers to knowledge transfer and improve the uptake of science into the decision making process.

2. Methods

2.1. Management plan review

To understand the extent to which primary science currently informs MPA management, and the relative importance of other knowledge types to inform management actions, we reviewed MPA management plans (where coral reefs are identified as a prominent benthic habitat) for three countries: Australia, Belize and Kenya. Individual MPAs and associated management plans were identified through web searches as well as through existing contacts with the relevant management organisations through the author group.

All of the identified management plans were read and analysed to understand the extent to which managers use primary science articles to inform their management actions. This was done by recording the number of references which were primary scientific articles (published in peer-reviewed international journals). We also recorded the number of references which were locally produced government documents (i.e. policies, strategies, plans and/or reports that were developed by the government agency responsible for managing the MPA in question), external technical reports, books or websites. Furthermore, as management agencies are often only responsible for a certain geographic region, MPA managers are likely to focus on issues most relevant to that location, and favour location-specific research. To assess the use of local information we also recorded the number of references (across all information sources), within each management plan that provided information specific to the location of the MPA.

2.2. Literature identification and data collection

To assess accessibility of MPA science to decision-makers we conducted a literature search using the database SCOPUS. We followed the search terminology identified in Jones et al. (2009); 'coral*' and 'marine protected area*' or 'coral*' and 'marine reserve*' or 'coral*' and 'no-take area*', limiting our search to all 'articles' and 'reviews' published between 1 January 2009 and 31 December 2012. The restricted time frame was chosen as this study is designed to explore the traits that currently constrain the uptake of MPA science by decision-makers rather than the historical trajectory of the discipline, and four years provided an adequate cross section of scientific literature currently being published (Fazey et al. 2005).

Each paper identified through the search was read for subject matter, and those that did not deal specifically with the topic of coral dominated MPAs were discarded. The remaining papers were then reviewed and analysed for specific information to assess:

1. The time taken for information to become available in published format from the reported date of data collection;
2. The ease of access to published information (free open access or subscription paywall); and
3. The ease of interpretation and application of the scientific findings presented in peer-reviewed scientific journals for management purposes.

To understand the timeliness in which primary science in relation to coral dominated MPAs becomes available to decision makers we reviewed all articles and quantified the number of months between the final date of data collection until the manuscript first became publicly available, either online or in print (following Fazey et al. 2005). We followed this methodology for two reasons. Firstly, data collection is deemed most relevant to decision-makers at the time of collection as it is at this point that it describes most accurately the state of the environment. Secondly, information on

whether a manuscript was submitted to alternate journals prior to being accepted and published is not readily available.

The issue of time taken to locate, access and read science is compounded when articles are in subscription only journals. To understand the extent to which this may constrain the use of science by MPA decision makers we identified the proportion of primary articles that were open access (freely available online) compared to those which are closed access (subscription only journals where manuscripts could only be viewed once purchased). We also quantified whether review articles were published in open or closed access journals.

Finally, we reviewed all articles and review papers to determine their relevance to management using qualitative content analysis (by adapting Fazey et al. 2005). For this purpose, we define management as the implementation and monitoring of specific conservation actions, for example, the restriction of certain types of fisheries gears. Each paper was given a score between one and three based on the degree to which it informed management. Specifically, the score was based on whether the manuscript identified a management need for the information and the data fulfilled this objective, and whether or not conservation and management recommendations/implications were articulated in the manuscript (modified from Fazey et al. 2005). A score of one was given where a paper did not fulfil either of these criteria, therefore considered to have no or low relevance to management. Scores of two were given where a paper identified a clear management need for the information, but was highly technical without deriving clear conservation recommendations. Scores of three were given where a paper both identified a clear management need for the information, as well as making specific management recommendations based on the results of the research in the discussion. Papers with a score of two are considered relevant to management, whereas papers with a score of three are considered highly relevant (Fazey et al. 2005).

The review of publications in this manner is inevitably subjective, and therefore to ensure consistency only the primary author (CC) reviewed and scored all papers. This author is well placed to do so having six years experience working on marine policies and programs for the Australian Government, including three years experience as a marine park manager. A second author who also works for an MPA management agency (SW) undertook an

independent assessment of a random subset of papers (10%) from our sample, over which an 82% agreement in scores was reached. The small number of discrepancies were discussed and addressed before the remaining papers were scored, ensuring the robustness of our scoring criteria (Bryman, 2012).

3. Results

3.1. Management plan review

Our search identified 35 MPAs where coral is a prominent feature of the benthos; 21 in Australia, 8 in Belize and 6 in Kenya. Of these 35 MPAs, 13 had current management plans (7 in Australia, 6 in Belize). While other MPAs had draft management plans, these were excluded from the analysis as they had not been endorsed and implemented by local authorities. As such, draft management plans varied greatly in their level of completeness, preventing meaningful and accurate interpretation of how information had been incorporated. Similarly, several management plans had expired at the time of data collection and were also excluded from analysis, as they do not necessarily reflect current choices in citing references.

The management plans cited 53 ± 8.3 (Mean \pm SE) information sources (Fig. 1). The majority were commissioned technical reports, which accounted for 52% of all references, followed by local government produced documents (i.e. policies, strategies, plans and/or reports that were developed by the government agency responsible for managing the MPA in question) which accounted for 23% of all references. Primary science was the third most used knowledge source, accounting for only 14% of all references. Other commonly cited information sources were books and websites (Fig. 1). Across all information sources, 74% of all references were based on information specific to the region relevant to the MPA.

3.2. Overview of publications

The SCOPUS search returned 234 primary scientific articles that included 12 review papers fitting the search criteria outlined in the methods. For the primary scientific articles, it took 40.2 ± 1.8 (Mean \pm SE) months from the completion of data collection until the article became available online or in print (whichever occurred first). Whilst most of the articles were published in subscription

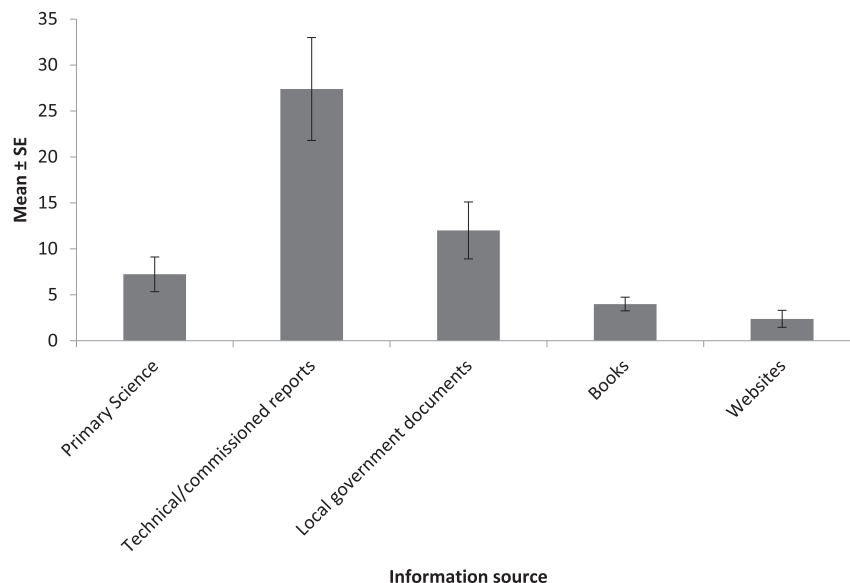


Fig. 1. Mean \pm SE number of each information sources cited in MPA management plans, based on review of current management plans across Australia, Belize and Kenya.

only (closed) access journals, 43% of articles were freely available. Similarly, 50% of review papers were open access.

Of the 222 non-review articles identified in the literature search only 12% were deemed as relevant (score of two) to the management of coral dominated MPAs, and 7% were considered to be highly relevant (score of three) (Fig. 2). This is despite the majority of papers including a sentence in the discussions stating that the results had important implications to MPA management. Rather, the majority of research articles did not typically establish management needs when framing or designing studies, and did not provide a clear conservation message or outline specific management actions in the manuscript, leaving managers to infer the implications independently. Articles which were deemed highly relevant to management (score of three) all included specific management recommendations that should be implemented in MPAs based on their findings, and many summarised these under distinct management sub-headings in the discussion.

In comparison, all 12 review papers were deemed useful at informing MPA management, with 25% of reviews deemed relevant to management while the remaining 75% were deemed highly relevant (Fig. 2). This is because review articles provided readers with a synthesis of research on a specific issue such as coral reef fisheries (Fenner, 2012) or the impacts of climate change (Keller et al., 2009), and critical assessment of a range of potential management options that could be implemented by MPA managers. Furthermore, reviews were less technical and did not require managers to make their own inferences from the results.

4. Discussion

Integrating primary scientific research into management actions remains a significant challenge for the management of natural resources (e.g., Cook et al. 2010; Lake et al. 2010). Accordingly, identifying and understanding the barriers to integration is critical for developing mechanisms to facilitate improved uptake of science by environmental practitioners. We provide an assessment of a range of potential barriers that might hinder the integration of primary scientific information into the decision making process using coral-dominated MPAs as a case study. Building upon previous work (e.g. Pullin et al. 2004; Cook et al. 2010), we found that peer-reviewed literature was not the predominant source of information cited in current coral-dominated MPA management plans. We find that this may be symptomatic of several issues

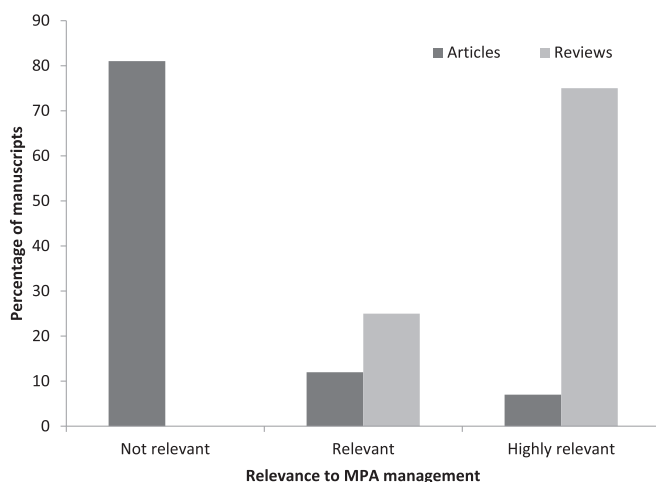


Fig. 2. Proportion of primary articles and reviews relevant and highly relevant to MPA management. Results based on review of 222 primary articles and 12 reviews published between January 2009 and December 2012.

associated with access to this primary scientific literature, such as the need for open access, mismatches in the timing of publication relative to the need for timely development of a management plan, and the extent to which primary literature provides clear suggestions for management actions. Such impediments to science accessibility are substantial, and may undermine the implementation of successful adaptive governance structures for natural resource management, especially on fast moving research fields such as climate change adaptation. Accordingly, improving the accessibility of primary scientific research and identifying more effective methods of knowledge transfer should be a priority for both environmental managers and researchers alike to ensure that successful adaptive governance structures can be implemented.

4.1. Use of primary science in management planning

Conservation science primarily aims to inform environmental practitioners about how best to manage species, their habitats, and the goods and services provided by the ecosystem. While most authors believe that their work is highly relevant to policy and management and is being used to guide decisions (Flaspohler et al. 2000; Ormerod et al. 2002), recent studies have shown decision makers rarely use scientific information when making policy and/or management decisions (e.g., Pullin et al. 2004; Young and Van Aard, 2011). Our findings for coral reef MPAs somewhat support this notion, with management plans rarely citing primary scientific information relevant to coral-dominated MPAs. Based upon patterns of citation in the management plans, it appears information is largely drawn from technical/commissioned reports and local government produced documents, whereby it is difficult to know whether the findings and their implications are peer reviewed and based on the summation from well designed experiments or personal judgement (Sutherland et al. 2004). However, assessing the relevance and robustness of technical reports to management outcomes was outside of the scope of the current study, and warrants future investigation. It should be noted, however, that many of the issues identified here may also affect consultants or others commissioned to write reports, where they too are seeking to use primary science.

Moreover, we found that almost three quarters of scientific information used in the development of management plans was based on data collected from the specific geographic region covered within the management plan. These results are similar to those reported by Young and Van Aarde (2011), who found that managers wanted science that was conducted in their reserves, and are less trusting of data collected elsewhere. This is not surprising in that management agencies are typically responsible for MPAs of a certain type or geographic region and local data may seemingly provide the most relevant information. However, given the geographic disparity in research effort for most biomes (Fisher et al. 2011) limiting information searches in this manner means that environmental practitioners may not be availing themselves of the full range of information and key lessons learnt from other areas of similar biome that could inform local management decisions.

4.2. Accessibility of primary scientific literature to environmental practitioners

Natural resource decision makers are typically focussed on practical outcomes, often within a political context and with their decisions open to public scrutiny (Simpson et al. 2008). As such, they are often faced with making decisions in relatively short timeframes, on the best available information that provides them with a clear and defensible way forward. It is therefore critical that decision makers have access to the most recent and scientifically

credible research available. However, we show that for coral-dominated MPAs, it typically takes more than three years from the completion of data collection for information to become available in the form of primary literature. This is comparable to the results presented by [Fazey et al. \(2005\)](#) who found that it takes on average four years for conservation science to be published after completion of data collection. Furthermore, once published only 43% of primary scientific articles and 50% of review papers relating to coral dominated MPAs were freely accessible to decision makers. The proportion of relevant freely accessible articles reported here is substantially greater than other sciences (cf. 17% of 1.66 million papers in [Laakso and Björk, 2012](#)), however, over half of the scientific literature is not freely available to decision-makers to consider when making decisions. The time lags reported here, in combination with restricted access to articles, can reduce the efficiency with which research can be incorporated into management decisions, hindering the implementation of successful adaptive governance structures. Clearly, improved approaches for rapid knowledge exchange are needed.

The time required to locate, access and read primary literature has also been identified as a barrier preventing the use of primary science by time-poor environmental practitioners (e.g., [Pullin et al. 2004](#)), prompting suggestions that a stronger emphasis should be placed on the systematic development of review papers to provide decision makers with comprehensive digestible and accessible information ([Pullin and Knight, 2001](#); [Sutherland et al. 2004](#)). We found that whilst review papers are routinely published in relation to coral-dominated MPAs and span a range of topics, they are often not developed systematically to build upon previous reviews. Moreover, review articles are likely to increase the time lag between data collection and information availability, as they are dependent on the collation of data and information from published primary literature. Accordingly, MPA decision makers are not provided with a consistent and reliable mechanism to reduce the time it takes to stay abreast of the scientific literature.

Finally, research findings presented in primary literature (review or otherwise) must be conveyed in a language easily accessible to managers for efficient uptake in management plans and decision-making processes ([Fazey et al. 2005](#)). Our analysis revealed that 81% of scientific papers relating to coral-dominated MPAs published during 2009–2012 did not clearly articulate the management-based need for the new information, nor did they clearly outline the implications of the research for ongoing and improved MPA management. This aligns with [Fazey et al. \(2005\)](#), who concluded that the majority of primary literature is too technical for environmental managers to interpret, and is not clear on how the results could influence management decisions. Clearly there is a need to develop better methods of science communication and knowledge transfer to facilitate the translation of new scientific information to management actions beyond the current model of research outputs focused upon peer-reviewed articles.

4.3. Implications of results and future recommendations

The findings reported in the present study have important implications for the future conservation of natural resources, suggesting that serious structural impediments to science accessibility undermine the implementation of successful governance structures for managing and conserving natural resources. Overcoming such barriers will require new and improved methods of knowledge transfer among academics and environmental practitioners. For this to occur, it is critical that the transfer of knowledge among stakeholders is viewed as a multi-directional process (e.g. [Roux et al. 2006](#); [Van Kerkhoff and Lebel, 2006](#)). Under this

model, both groups are accountable for ensuring that research needs and findings are clearly articulated, freely available and understandable to all stakeholders. For academics, this means not relying on publications as the primary means of knowledge transfer, but rather using alternate approaches such as social media or targeted briefs and/or presentations delivered directly to the appropriate end user. Social media in particular, has revolutionised opportunities for communication, networking and idea sharing ([Thaler et al. 2012](#); [Darling et al. 2013](#)), and is already used by scientists to share knowledge with a range of end-users (e.g. [Ogden, 2013](#)). Academics could strive to publish their research in journals that provide open access options and expedited review periods to improve its accessibility to end-users. In turn, management agencies should endeavour to provide their staff with the means to access and interpret the scientific literature, and recognise the value of a science background and/or technical skills as a prerequisite for management roles in natural resource management ([Risk, 1999](#)).

Achieving improved information flow, while simple in concept, can often prove difficult and requires decision-makers and scientists alike to move beyond traditional approaches to information sharing ([Seavy and Howell, 2010](#); [Cook et al. 2013](#)). One well recognised approach to improve information flow and knowledge transfer among academics and resource managers is through the co-production of knowledge, whereby managers actively participate in scientific research programs (e.g. [Ceccarelli et al. 2011](#); [Hoey et al. 2011](#); [Underwood et al. 2013](#)). Under this approach, decision-makers are actively engaged in research programs from the outset, ensuring that the information requirements of both groups are discussed and jointly understood before the execution of a study. Dialogue should be maintained as the research progresses and, where possible, all parties should be involved in the development of reports and recommendations. Closer collaboration between decision-makers and academics will ensure that both groups have some level of ownership over the information produced from the research, and that the research is relevant to management with direct application to both operational and decision-making processes. Indeed, widespread efforts to encourage and facilitate the co-production of knowledge are already underway, for example, through collaborative identification of knowledge needs by scientists and managers (e.g. [Beger et al. 2011](#); [Cvitanovic et al. 2013](#)).

One well documented example of how the co-production of knowledge can improve knowledge transfer and science uptake into the decision-making process can be found in relation to coral reef MPA research and management via the Cooperative Research Centre for the Great Barrier Reef World Heritage Area (Reef CRC) (reviewed by [Woodley et al. 2006](#)). The Reef CRC was established in Australia in 1999 to promote and support the ecologically sustainable development of the Great Barrier Reef World Heritage Area, Torres Strait and tropical reef ecosystems along Australia's east coast. This was achieved through an integrated program of applied research and development, education, training and extension to enhance the viability of reef-based industries and management bodies. All partners to the Reef CRC, including management bodies, industry representatives and community groups, were unanimous in their views that the CRC had achieved its stated mission at the highest level ([Woodley et al. 2006](#)), emphasising the success of this approach.

Another approach to improve information flow among scientists and decision-makers is through the use of knowledge brokers or boundary organisations that develop relationships and networks with, among, and between producers and users of knowledge ([Guston, 2001](#); [Meyer, 2010](#)). While the exact role and function of knowledge brokers and boundary organisations 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 (Michaels, 2009). An extensive body of literature outlining the potential value of these roles already exists, and recent empirical evidence demonstrates their utility in knowledge transfer (Crona and Parker, 2012). For example, California has established the California Ocean Science Trust, a non-profit boundary organisation mandated to support ocean and coastal management decisions with the best available science (Pietri et al. 2011). Accordingly, future investment in these types of roles and/or organisations is likely to result in greater uptake of science by decisions-makers.

Finally, the transfer of knowledge to decision-makers could be enhanced through innovative mechanisms for rapidly transferring information. For example, the recent advocacy for layperson summaries and research highlights by publishers of peer-review research has been used to increase the public communication of science (Pellechia, 1997; Suleski and Ibaraki, 2010). Similar advocacy for translation of articles to management outcomes could be provided by the explicit inclusion of management summaries on a free open access part of journal websites (i.e., as is currently the case for abstracts). Concurrently, research funders could insist through contractual obligations that the options outlined above are implemented as part of a research program, and provide adequate funding for the implementation of these activities. Some progress to this effect has already been made and could provide a model for other funding agencies globally. For example in Australia, the Australian Research Council (ARC) has introduced a new open access policy for ARC funded research, requiring that any publications arising from an ARC supported research project must be deposited into an open access institutional repository within a 12 month period from the date of publication. Similarly 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 for in the proposal.

Improving the accessibility of primary science to environmental managers will require novel approaches to knowledge transfer. This should include institutional innovation by publishers and funding agencies to promote and reward scientists for engaging decision-makers in their science on an equal footing with traditional metrics, such as peer-reviewed outputs (Weiss, 2007). While developing the right metrics to encourage impactful management outcomes as well as scientific outputs may be challenging, this is likely to result in the improved knowledge flow among scientists and natural resource managers needed to support adaptive governance structures.

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