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perspective

Lessons learned at the interface of marine ecology and environmental management in Australia

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ABSTRACT.—Marine scientists and environmental managers engaged in a roundtable discussion at the Australian Marine Sciences Association conference in July 2014 to identify areas where linkages could be improved between the two groups. Here, we summarize the key themes and outcomes from the discussion, including the need to clearly define management objectives, to identify the scale of the issue, to conduct effective science communication, to address uncertainty, and to perform iterative engagement. We also discuss some of the challenges inherent in establishing new linkages, and provide a set of examples where effective collaborations have been achieved between marine ecologists and environmental managers working in Australia.

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At the Australian Marine Sciences Association conference held in Canberra, Australia in July 2014, marine ecologists specializing in population connectivity (e.g., the degree of demographic or genetic connectedness between populations; Cowen and Sponaugle 2009, Kool et al. 2013) and marine environmental managers engaged in a roundtable discussion to identify areas where linkages could be improved between them on the basis of their shared experience. Although the discussion was initially framed in the context of connectivity science, the issues discussed are broadly applicable to other topics at the interface of science and management. Here we summarize the key themes and outcomes from the discussion.

Defining Operational Objectives.—It is important to have clear operational management objectives with benefits and costs that can be measured (Tear et al. 2005, Day 2008). Operational objectives will typically support broader policy objectives that may be difficult to evaluate directly (Sainsbury et al. 2000). Operational objectives with strong ties to policy objectives help focus research resources on the collection and delivery of information that is useful and timely, and we strongly recommend that scientists and managers meet and consult with one another when framing operational objectives that support hypotheses and quantitative evaluation. Placing the objectives within a quantitative framework where possible helps to prioritize different management options, and to evaluate trade-offs between pursuing and implementing different objectives (Nicholson and Possingham 2006). High-level policy objectives may include, but are not limited to: protecting representative habitats and populations (McNeill 1994); preserving genetic diversity, including rare, endemic or charismatic species (Gray 1997); mitigating threats to biodiversity such as the spread of introduced species (Bax et al. 2003); maintaining ecosystem resilience (Levin and Lubchenco 2008); supporting ecosystem services (e.g., nursery grounds; Palumbi et al. 2009); and preserving natural systems as scientific reference sites (Halpern and Warner 2002). Operational objectives sit below these broader policy objectives and provide a quantitative basis for evaluating alternative management options (e.g., increasing habitat area or population size by x% over y years). Developing operational objectives for more ambitious policy objectives, such as maintaining ecosystem resilience, can be extremely challenging. The form of the operational objectives will direct research design, affect required resources, and influence the interpretation and communication of research results. Strong links between operational and higher-level policy objectives are also essential to ensure that progress toward achieving broader strategic goals (e.g., protecting representative habitat) can be evaluated. While environmental information provides an important foundation for refining operational objectives and informing management decisions, social and economic information also have roles that may be as or more important than the environmental information depending on the local political and governance structure.

Determining the Scale of the Issue.—Clear objectives help define relevant scales of scientific and management interest (Tear et al. 2005). Scaling applies not only to space and time, but also to biological hierarchies (e.g., different trophic levels, life-history stages), sociopolitical entities (e.g., local, state, regional, national, and international), and economic considerations (micro- and macro-economic; e.g., Mantegna and Stanley 1995). There may be a need to resolve mismatches among these different scales (Crowder et al. 2006, Cumming et al. 2006). For example, biological systems frequently operate on temporal scales of decades to centuries, whereas political decisions typically operate on a three to five year time cycle. Consequently, government interventions can change relatively quickly whereas natural systems may take decades or centuries to respond to or recover from disturbances. Understanding the scales of scientific and management interest will also provide scope for following dependencies among the components of a system—for example, when evaluating habitat dependencies, food webs, or market value chains (Kaplinsky and Morris 2001). This in turn will help in delineating appropriate spatial and temporal limits when collecting and reporting information to be used in helping to implement or measure the effect of management actions. Dependencies will also occur at different administrative levels. For example, national-scale objectives may need to be considered within the context of larger framework agreements (e.g., the UN Convention on Biological Diversity or CITES; Wells et al. 2008, Vincent et al. 2014), and in light of how they link to fine-scale efforts, such as the development of environmental impact assessments.

Communicating Science Effectively.—Scientists must be able to clearly articulate how their research is relevant to management, including how it will inform decision-making processes, whether this involves providing tools, processes (e.g., monitoring strategies, recommendations for mitigating impacts), or a better understanding of the system. An important aspect of this involves presenting information in a compelling and readily understood manner at an appropriate time that addresses the needs of managers and government decision-makers (Weingart 1999, Grorud-Colvert et al. 2010). This may be in the form of briefing notes, presentations, non-technical overviews, round-table discussions, or by interfacing directly with the information system that managers use to make decisions. Scientific information must be communicated to multiple management levels (and often not by the researchers themselves) in the face of strongly competing interests facing decision-makers with limited time and availability. Furthermore, it cannot be taken as given that managers and government officials possess extensive scientific training. Their background may lie in other areas, such as policy or law, leading to a need for cross-disciplinary communicators to express the scientific information in the language used by the officials. Scientists should also cultivate an understanding of the governance responsibilities, both within the management agency and their own organization, so they can identify how to communicate their science so it is available at the time and place that decisions are being made.

Addressing Uncertainty.—Characterizing and addressing uncertainty in our understanding of natural systems is a key part of the decision-making process, and should not be ignored (Grafton and Kompas 2005). However, the various aspects of uncertainty do need to be conveyed in a clear manner. This should not be interpreted as "dumbing down" information, but rather as providing a transparent and concise synthesis of different aspects of variability and how it is likely to influence the success of alternative decisions. There are many examples of how this can be achieved from polling studies (e.g., Gallup 2015) and risk assessments for insurance (Knight 2013). In addition, the language, approaches, and reporting methods used in these disciplines will be familiar to policy makers and economists. Capturing and communicating uncertainty is an area in which fisheries scientists have become particularly adept (e.g., Punt and Hilborn 1997, Sainsbury et al. 2000). Reporting should also make the distinction between uncertain and unknown information and the degree of effort and resources that would be required to reduce uncertainty to acceptable levels, or indeed whether it would be achievable. Scientists and managers should engage in adaptive management practices, and be pragmatic with respect to specifying which components of the environment can be reasonably measured, predicted, and managed, and which cannot.

Staying Connected.—Exchange between scientists and managers needs to be iterative. Iterative engagement will help with responding in an effective manner to shifting priorities (on the part of both scientists and managers), and in updating the decision-making process with newly acquired sources of information. Supporting and communicating scientific research inside the multiple levels of management agencies may often require an internal champion committed to achieving that outcome; however, this is not always easy to achieve. Establishing new points of contact can be challenging, but can help spark new ideas and synergies. Scientists and managers need to create and take advantage of networking opportunities (e.g., through meetings, seminars, targeted group communications, or social media groups), particularly with a view to developing contacts outside long-established channels. Reflection on the outcome of the decision-making process will help identify new or refine existing management actions and policy, refine operational objectives, and to focus data collection efforts (Pressey et al. 2013). It is also important to recognize that while scientists have a tendency to pursue large and challenging areas of research (since that is where novelty is often found), more direct societal value can often be found in smaller improvements. Improved monitoring will lead to a better understanding of system dynamics, which in turn will lead to the ability to make better and timelier decisions. Establishing more effective linkages between researchers and government will lead to more effective environmental outcomes and increase the impact of scientific research.

Challenges.—Although improving communication among marine scientists and environmental managers should be encouraged, it is also important to recognize the reasons why barriers between the disciplines tend to be the default. Resourcing (e.g., time, money, staff) is a constant constraint in any environment, and while activities such as cross-disciplinary engagement can spark the development of new ideas, they impose costs in terms of time and resources. Additionally, the degree to which new information will ultimately prove useful can be highly uncertain. We suggest that resources be designated for planning and interactive engagement during the initial stages of project development, periodic review and adjustment, and a final review to identify whether project actions achieved measureable and useful outcomes in terms of evaluating performance against or providing improved options to support clear policy objectives. Another challenge will lie in resolving different measures of performance. For example, scientists emphasize the cultivation of new knowledge (Bruneel et al. 2010), with scientific output acting as a key measure of performance (Becher and Trowler 2001), whereas the effectiveness of public administrators and their departments is often evaluated through public approval and engagement. Both of these are in contrast to industry, which typically has the goal of seeking profitability and competitive advantage (Cooke and Leydesdorff 2006). Incompatible goals may lead to unwillingness to share information, especially when novel approaches or intellectual property are being developed, and lack of agreement regarding shared direction is likely to result in hindered progress and a continuation of the status quo. However, if different measures of performance can be aligned, then incentives arise for resource sharing and collaboration. It is also important to recognize that science-management collaborations that take place in developing countries are likely to involve an even broader range of considerations than those discussed here, such as the degree to which local partners can effectively participate and have standing in the process (Pomeroy and Douvere 2008), the need to consider available infrastructure that could support the communication and implementation of research results, and enforcement of recommendations if needed. It is a sad fact that much good science is achieved in developing countries by visiting scientists, but the impact is lost because there is little follow-up or continued engagement to support the local government to implement and monitor proposed actions.

Examples of Progress.—Although pointing out areas for change tends to be easier than providing concrete examples of productive collaboration and action, we are nevertheless able to provide several cases of positive engagement between marine ecologists and environmental managers in Australia on the basis of our collective experience. With respect to collaborative objective setting, the Commonwealth Environment Research Facilities (CERF) and National Environmental Research Program (NERP) offer examples where objectives were strongly tied to departmental interests from the outset. Among these were: a genetic study of abalone (*Haliotis* spp.) to identify the spatial and temporal scales associated with population recovery (Miller et al. 2009); and a comprehensive biogeographic survey of seafloor fauna to help quantify the representativeness of Australia's marine reserve network (O'Hara et al. 2011). Campbell et al. (2015) explicitly note the importance of iterative refinement of proposals, knowledge-brokering, and follow-up reporting in these research programs, and the long-term benefits of shared goals, dialogue, trust, continuity, and program flexibility. To help with identifying appropriate biological scales of interest, a broad range of new technologies have been developed; for example, DNA analysis techniques are being used to assess dispersal linkages for metapopulation analysis of fisheries, thereby allowing the spatial scale of management units to be set appropriately (Fogarty and Botsford 2007). Active communication and iterative engagement were required in response to the spread of *Asterias* spp. to Tidal River at Wilsons Promontory in Victoria. Multiple government agencies (Parks Victoria, Victoria's Department of Environment and Primary Industries, and Environment Protection Authority Victoria), researchers (University of Melbourne and Deakin University), and a large number of volunteers collaborated to use a variety of sampling approaches (e.g., plankton surveys, modeling, sonar mapping, biological surveys) to assess potential source population locations, the possible impacts of infestation, risk of further spread, and the effectiveness of the control program (Hirst et al. 2013; Howe, Parks Victoria, pers comm). Another example is provided by a multi-partner project led by the University of Tasmania to investigate the biotic connectivity of subtidal reefs in southeast Australia. The work integrated broad spatial-, temporal- and taxonomic-scale data sets with phylogenies and taxonomic expertise to investigate how marine processes influence connectivity and the distribution of marine fauna around the southeast coast, with the aim of informing marine protected area network design and management (c.f. Barrett et al. 2009). In Western Australia, oceanographic larval studies identified that the commencement of spawning was important in understanding western rock lobster (*Panilurus* spp. and *Jasus* spp.) settlement, which was later confirmed by a separate statistical assessment (de Lestang et al. 2014). The work was also able to examine the relative importance of spawning stock from different areas of the coast, and the degree of associated variability, which was then built into the harvest strategy of the fishery (Caputi, WA Department of Fisheries, pers comm). Researchers (Deakin University, University of Tasmania, University of

Six steps to common ground

1. *Consult and collaborate with managers while designing research, rather than developing tools or collecting information that may not be used.*
2. *Agree on common definitions, define clear scales of interest, exchange management and scientific objectives, and identify measurable costs and benefits.*
3. *Articulate specifically and clearly how research will support the decision-making process, whether by providing tools, processes (e.g., monitoring strategies, recommendations for mitigating impacts), or a better understanding of the system.*
4. *Communicate data, results, and knowledge in ways that are relevant, clear, timely, engaging, and accessible to managers. Create concise executive summaries with links to detailed information where helpful. Consider pursuing networking opportunities outside of traditional channels.*
5. *Characterize and address uncertainty. Managers can make use of the level of certainty associated with assessment tools in their decision-making process. Scenario setting can be used to provide a range of options to managers rather than advocating a single course of action.*
6. *The exchange between scientists and managers needs to be iterative. Managers may need to see tools in practice and their limitations before putting them to work.*

Melbourne) are also collaborating with fisheries agencies and industry using a combination of seafloor habitat and genetic data, and hydrodynamic models to examine population connectivity of commercially important species such as abalone (Ierodiaconou, Deakin University, pers comm). These are only a few select examples of active engagement between marine ecologists and environmental management in Australia based on our personal experience with connectivity research; however, they do demonstrate ongoing collaboration between the two groups, and serve as a foundation for strengthening ties moving forward.

Conclusion.—Through sharing some of the lessons we have learned as marine ecologists and environmental managers, we hope to draw attention to ways of improving collaboration and communication between the two groups with a view to improving the overall effectiveness of conservation and environmental outcomes. We have found that iterative engagement of scientists and managers, from early stages of planning through to the delivery of final product, identifies key research needs to: support development and implementation of clear and measureable objectives; determine the appropriate scale of the work; identify means of explicitly addressing uncertainty; and ascertain how and when to communicate results in a clear and concise manner. Although real barriers exist that have the capacity to hinder collaboration among the groups, we believe that the potential costs associated with overcoming them are greatly outweighed by the long term benefits of aligning priorities, sharing information and working collaboratively to achieve outcomes with greater impact.

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