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Research article

# From science to action: Principles for undertaking environmental research that enables knowledge exchange and evidence-based decision-making

C. Cvitanovic [a, *], J. McDonald [a, b], A.J. Hobday [a, c]

[a] Centre for Marine Socioecology, University of Tasmania, Battery Point, Tasmania, 7004, Australia
[b] Faculty of Law, University of Tasmania, Battery Point, Tasmania, 7004, Australia
[c] Oceans and Atmosphere, CSIRO, Hobart, Tasmania, 7001, Australia

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ABSTRACT

Effective conservation requires knowledge exchange among scientists and decision-makers to enable learning and support evidence-based decision-making. Efforts to improve knowledge exchange have been hindered by a paucity of empirically-grounded guidance to help scientists and practitioners design and implement research programs that actively facilitate knowledge exchange. To address this, we evaluated the Ningaloo Research Program (NRP), which was designed to generate new scientific knowledge to support evidence-based decisions about the management of the Ningaloo Marine Park in north-western Australia. Specifically, we evaluated (1) outcomes of the NRP, including the extent to which new knowledge informed management decisions; (2) the barriers that prevented knowledge exchange among scientists and managers; (3) the key requirements for improving knowledge exchange processes in the future; and (4) the core capacities that are required to support knowledge exchange processes. While the NRP generated expansive and multidisciplinary science outputs directly relevant to the management of the Ningaloo Marine Park, decision-makers are largely unaware of this knowledge and little has been integrated into decision-making processes. A range of barriers prevented efficient and effective knowledge exchange among scientists and decision-makers including cultural differences among the groups, institutional barriers within decision-making agencies, scientific outputs that were not translated for decision-makers and poor alignment between research design and actual knowledge needs. We identify a set of principles to be implemented routinely as part of any applied research program, including; (i) stakeholder mapping prior to the commencement of research programs to identify all stakeholders, (ii) research questions to be co-developed with stakeholders, (iii) implementation of participatory research approaches, (iv) use of a knowledge broker, and (v) tailored knowledge management systems. Finally, we articulate the individual, institutional and financial capacities that must be developed to underpin successful knowledge exchange strategies.



## 1. Introduction

The growing urgency and complexity of conservation problems present a significant challenge to managers and decision-makers (Sardar, 2010; Parrott and Meyer, 2012). Often described as 'wicked problems', these issues are characterised by high levels of uncertainty, contested values and political and administrative uncertainty (Hughes et al., 2013; Game et al., 2014). As a result there have been calls for new flexible, integrated and evidenced-based approaches to management and governance that can holistically deal with the complexity of social-ecological systems and the goods and services they provide (Sutherland et al., 2004; Hughes et al., 2005; Mahon et al., 2008; Pahl-Wostl, 2009). Underpinning this is the extent to which conservation practitioners can access, interpret and integrate new scientific knowledge into decision-making processes via efficient and effective knowledge exchange among scientists and decision-makers (Cvitanovic et al., 2015a). In this regard, knowledge exchange is defined as the two-way exchange of knowledge between scientific 'producers' and 'users' (Mitton et al., 2007), and encompasses all facets of knowledge production,

* Corresponding author.
*E-mail address:* christopher.cvitanovic@utas.edu.au (C. Cvitanovic).

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sharing, storage, mobilization, translation and use (Best and Holmes, 2010). Indeed, in the conservation and resource management sectors, knowledge exchange is increasingly recognised as a key factor facilitating the social, environmental and economic impacts of scientific research (reviewed by Fazey et al., 2013).

In recognition of the need to link conservation science to action, an emergent body of literature has sought to identify and overcome the barriers impeding knowledge exchange among scientists and decision-makers (e.g. Kareiva et al., 2002; Briggs, 2006; Shanley and López, 2009; Laurance et al., 2012; Cvitanovic et al., 2015b). Growing awareness of the importance of knowledge exchange has also led to increased efforts by conservation scientists and decision-makers to implement strategies that support knowledge exchange and lead to evidence-based decision-making (Pietri et al., 2011; Cook et al., 2013; Van der Molen et al., 2015). However, despite these efforts, recent evidence suggests that the integration of science into conservation decision-making processes remains a significant challenge (e.g. Cook et al., 2010; Cvitanovic et al., 2014a; Addison et al., 2015). As discussed by Reed et al. (2014), this is because while our conceptual understanding of knowledge exchange has advanced, there remains very little guidance to help scientists and decision-makers design and implement conservation research programs that actively facilitate knowledge exchange. As a result knowledge exchange activities are typically undertaken on an *ad-hoc* basis, with very little theoretical, methodological, or empirical grounding (Reed et al., 2014; Boschetti et al., 2016).

Developing guidance to help conservation scientists and practitioners design and implement research programs that actively facilitate knowledge exchange can be achieved through the evaluation of previous research programs that have attempted to link science to action (Meagher et al., 2008; Phillipson et al., 2012; Fazey et al., 2014; Reed et al., 2014). Such evaluations are necessary to elucidate the factors and processes influencing the effectiveness and efficiency of knowledge exchange activities (Connick and Innes, 2003; Dobbins et al., 2009; Laycock et al., 2011), and identify the core capacities required to support and facilitate knowledge exchange processes (Van Kerkhoff and Lebel, 2015). In this regard, capacities includes both the capability to act and the competences required to do so (Franks, 1999), and encompasses the full suite of individual, organisational, social, political, material, technical, practical and financial elements required to support knowledge exchange activities (Eade, 2007). Evaluations of knowledge exchange processes are seldom undertaken, however, given that successful outcomes are difficult to define and measure, and may occur sometime after a program has concluded (Fazey et al., 2013).

To develop empirically grounded guidance to help conservation scientists and decision-makers design and implement conservation research that actively enables knowledge exchange we undertook an extensive evaluation of the Ningaloo Research Program (NRP). Commencing in 2006, the NRP was an intense program of marine research valued at AUD$36 m of funding, explicitly designed to generate new knowledge for the Ningaloo region in north-western Australia, so that conservation practitioners could make more informed decisions about the management of the Ningaloo Marine Park and surrounding area ahead of its nomination as a World Heritage Area in 2011. The program was large in scale and interdisciplinary in nature, with 40 individual research projects in four overarching themes; biodiversity, physical environment, socio-economics and human use, and management support tools.

In undertaking this evaluation of the NRP there were four primary research objectives. These were to evaluate the (1) program outcomes, including the extent to which the science generated through the program has subsequently informed management decisions; (2) the barriers that prevented efficient and effective knowledge exchange among scientists and managers involved in the NRP; (3) the key requirements for improving knowledge exchange processes in the future; and (4) the core capacities that are required to support knowledge exchange processes. By focusing on a single conservation research program this study elucidates the perspectives and experiences of all program participants to provide a comprehensive and in-depth understanding of all of the factors that influenced knowledge exchange among conservation scientists and decision-makers. In doing so this study complements and builds upon Reed et al. (2014), who evaluated knowledge exchange activities across multiple research programs using a relatively small number of participants from each program. This approach also allows us to generate a set of key design principles to guide the development and implementation of future conservation research programs to enhance the related decision-making processes.

## 2. Methods

### 2.1. The Ningaloo region

The Ningaloo Region is home to the Ningaloo Marine Park, which encompasses Australia's largest fringing coral reef running 300 km along the coastline between Exmouth and Red Bluff. This area is a global biodiversity hotspot and in 2011 the Ningaloo Coast was inscribed on the World Heritage List in recognition of the 'outstanding universal value of the area'. The Ningaloo region is also a premier tourist destination and a key service point for oil and gas development and exploration, as well as supporting two permanent communities in Exmouth and Coral Bay. Given the multiple and competing uses of the region its conservation and management presents a significant challenge for decision-makers.

### 2.2. Data collection and analysis

To gather information relevant to the four objectives we used a qualitative research approach to develop an in-depth understanding of the experiences of participants in the NRP (Bryman, 2012). This involved conducting semi-structured interviews of participants recruited using a purposive snowball sampling technique between November and December 2016 (Noy, 2008). The initial group of participants was identified by the Science Coordinator responsible for the implementation of the NRP, who identified lead decision-makers and scientists involved in the program. At the completion of each initial interview, participants were asked to suggest others they believed would be relevant to the study, with this step being repeated at the completion of each subsequent interview. Any individual who was recommended more than once was invited to take part in the study. This approach yielded 24 names, three of whom were unable to be contacted as they had moved into new roles and their contact details were unknown. Thus, a total of 21 participants were interviewed: seven locally-based (Exmouth) decision-makers responsible for the day-to-day management and operation of the Ningaloo Marine Park, seven remotely-based (Perth) decision-makers involved in the long-term strategic decision-making associated with the management of the Ningaloo Marine Park, and seven chief scientists who led research activities within the NRP. The decision-makers spanned three different government agencies representing both State and local levels of government, and the seven scientists were from four separate Australian research institutions. For the purpose of analysis these groups were treated together as preliminary analysis showed no significant differences between their 'group' responses.

Prior to starting each interview, the purpose of the research was explained to the participant and formal written consent to participate was obtained (in accordance with Human Research Ethics procedures TSSHREC: H0015336). In general, each interview took

between 45 and 60 min and was undertaken by the lead author. Each interview was guided by a set of questions that were designed explicitly to explore the perceptions of participants against each of the four study objectives, and by previously published evaluations of knowledge exchange activities (Reed et al., 2014) (full interview guide available at Appendix A). All interviews were audio recorded and professionally transcribed to ensure accuracy.

Interview transcripts were analysed using NVIVO 10 qualitative data analysis software. The analysis consisted of broad thematic coding against the four objectives:

1. What were the outcomes of the Ningaloo Research Program?
2. What were the main barriers that prevented knowledge exchange between scientists and decision-makers in the Ningaloo Research Program?
3. How should conservation research programs be designed in the future to improve knowledge exchange and the capacity for evidence-based decision-making?
4. What capacities and competencies are required to support knowledge exchange activities associated with conservation research programs?

To ensure themes were relevant and valid, the emerging interpretations were continually checked against the data from which they were derived, following previous methods (e.g.-Fleming and Vanclay, 2009; Marshall et al., 2011; Cvitanovic et al., 2016).

## 3. Results

The interview coding produced 13 themes that mapped to each of the four research objectives (Table 1). Although there was some overlap between themes, this approach identified the key outcomes of the NRP, the barriers to knowledge exchange experienced in the NRP, the key requirements for designing conservation research programs that actively facilitate knowledge exchange, and the core capacities required to underpin and enable knowledge exchange among scientists and decision-makers. It is important to note, however, that the number of references simply indicates how frequently each theme was mentioned in interviews, rather than the importance participants placed on the issues. Specific issues with each objective are addressed in the following sub-sections.

### 3.1. Outcomes of the NRP

Interview analysis produced two themes relating to the outcomes of the NRP; the extent to which the program generated new science relevant to management, and the ways in which the program led to a more engaged local community (Table 1). Of these, participants spoke most frequently about the extent to which the program generated an expansive and comprehensive new body of science that is highly relevant to the management of the Ningaloo Marine Park (Table 1, Theme 1a): *' … it produced a huge amount of new knowledge … everything from habitat mapping to biodiversity surveys, understanding key ecological processes, community structures, et cetera.'* (ID8). This was reiterated by another participant who stated that: *'I can't think of a single bit of research that came out of the program that didn't have inherent value'* (ID13). In particular, participants identified research into the effectiveness of current sanctuary zones within the Marine Park, including the identification and mapping of critical habitats within the marine park, as critically important to management *' … based on our new understanding you should see a redefinition of the sanctuary zones within the marine park … at the moment all of the sanctuary zones are inshore, and in reality they need to go right across the marine park to link with the Commonwealth waters'* (ID20). Participants also commonly spoke about the importance of the socio-ecological models developed through the program, and their ability to provide spatial information to managers in terms of human use and pressure throughout the region. In speaking about the new knowledge generated through the NRP and its relevance to management, participants also identified a range of physical outputs that were developed to share the knowledge with decision-makers. This included the development of the *Ningaloo Atlas*, which was designed to provide infrastructure and tools to promote the free and open exchange of information generated through the NRP to conservation practitioners. Participants also outlined a range of other outputs from the NRP, including annual milestone reports for each project, peer-reviewed manuscripts, and research summaries that were specifically designed to communicate the key findings of each research program in lay terms to decision-makers.

In addition to an increased scientific understanding of the region, participants also noted a range of other positive outcomes associated with the NRP, and in particular, the extent to which the program led to a more informed and better engaged community (Table 1, Theme 1b): *'It educated the community which led to a feeling of ownership and custodianship of the local area'* (ID1). In turn, participants believe that this sense of custodianship will have positive flow-on impacts to management, with one participant commenting that: *'If the public understand it more, they appreciate it more and they have a better capacity to manage it themselves* (ID8). Participants also believe that the NRP had beneficial impacts on the local

**Table 1**
Analysis hierarchy of themes derived from interviews with Ningaloo Research Program participants. Frequency is the number of times a theme was coded across all interviews, while the number of participants represents the number of unique interviewees who raised the theme (total interviewees = 21).

| Research objectives | Theme | Frequency | No. of participants |
|---|---|---|---|
| 1. Outcomes of the NRP | a. Science relevant to management | 55 | 21 |
| | b. More informed and engaged community | 18 | 11 |
| 2. Barriers to knowledge exchange experienced in the NRP | a. Cultural differences between scientists and decision-makers | 41 | 17 |
| | b. Institutional barriers within decision-making agencies | 62 | 16 |
| | c. The inaccessibility of science to decision-makers | 39 | 15 |
| | d. Poor program planning during the development phase of the Ningaloo Research Program | 35 | 15 |
| | e. Geographic isolation | 21 | 7 |
| 3. Key considerations for designing conservation research that enables knowledge exchange | a. Design and development phase | 57 | 20 |
| | b. Implementation Phase | 117 | 19 |
| | c. After the completion of the program | 30 | 13 |
| 4. Core capacities needed to support knowledge exchange | a. Individual capacities | 46 | 17 |
| | b. Institutional capacities | 25 | 8 |
| | c. Financial capacities | 14 | 11 |

tourism sector, by raising the profile of the region on a global scale and highlighting it as an ecologically important area: '*… it certainly raised the profile of Ningaloo Reef and the Ningaloo Marine Park on a global level … and increased levels of tourism in the region*' (ID10). Other positive outcomes of the NRP included the extent to which it provided an opportunity for scientists to develop skills in relation to stakeholder engagement, including opportunities for student participation and training.

### 3.2. Barriers to knowledge exchange in the NRP

While the NRP generated an extensive body of new scientific knowledge relevant to the management of the Ningaloo Marine Park, participants stated that to date, very little of this knowledge had been successfully exchanged with decision-makers and incorporated into decision-making processes. Rather, most participants outlined a range of barriers that had prevented knowledge exchange among scientists and decision-makers. Five key themes emerged from these responses: (a) cultural differences between scientists and decision-makers, (b) institutional barriers within decision-making agencies, (c) the inaccessibility of science to decision-makers, (d) poor program planning during the development phase of the NRP, and (e) the geographic isolation of the Ningaloo Marine Park (Table 1).

The most significant barrier to successful knowledge exchange between scientists and decision-makers, identified by 17 of the 21 participants, was cultural differences between the two groups (Table 1, Theme 2a). For example, participants noted that decision-makers are required to be responsive and focused on day-to-day operations, and that this limited the time that they had available to stay abreast of new knowledge relating to the marine park: *'As a manager you need to be super responsive …. so a lot of the time you are responding to things rather than planning … so you don't have the luxury of staying across the science*' (ID5). Participants spoke about the ways in which the 'publish or perish' culture in the research community undermines knowledge exchange activities, as scientists are forced to focus their efforts on academic outputs rather than stakeholder engagement activities. Closely associated with this was the extent to which scientists must 'follow the funds', and as such their engagement with decision-makers following the completion of the project is limited: *'Scientists are always being forced to look for the next funding stream, so by the time this project ended, many had moved onto the next thing … they were unable to finalise and communicate their findings as well as they could have*' (ID14).

Participants also identified several institutional barriers to knowledge exchange within the various managements agencies involved in the NRP (Table 1, Theme 2b), particularly issues associated with organisational hierarchy and leaders that did not support knowledge exchange activities. For example, participants identified that some individuals within leadership positions across the various decision-making agencies prevented decision-makers from actively participating and co-producing the science, to the detriment of knowledge exchange: '*… key individuals within leadership positions prevented decision-makers from coming into the field and participating in the research … if this had occurred, it would have ensured that the research we did was actually the research they needed, and they would have been able to use the data seamlessly*' (ID15). Complex institutional structures were also found to have inhibited communication among different groups in the same agency, particularly between staff based in the head office (Perth) and regional offices (Exmouth).

Another commonly discussed barrier to knowledge exchange in the program was the inaccessibility of science to the decision-makers (Table 1, Theme 2c). This was an issue of timing, the form of science outputs, and ease of availability. Managers spoke about the extent to which time lags between data collection and availability prevented them from using research findings: *'Another big barrier is the timeframes … managers might have a question now, but by the time the scientist has the information ready the manager has found another way to deal with the problem and moved onto another issue*' (ID10). Even when program outputs were readily available, some participants felt that they did not clearly articulate the implications of key findings to the management of the Ningaloo Marine Park in a manner that was understandable by decision-makers. This was compounded by a lack of skills and expertise (e.g. - no scientific training) among decision-makers to interpret and apply the knowledge in decision-making processes. Finally, several participants reported that outputs from the program were not consolidated and easily discoverable.

Poor program planning during the design phase was identified as a key barrier that undermined knowledge exchange activities (Table 1, Theme 2d). Most commonly, participants attributed this to the fact that research questions were not co-developed or end-user driven, and thus the knowledge generated did not necessarily match the knowledge needs of decision-makers: *'Some of the research that had been done really wasn't what was needed … it was what the researchers wanted rather than the management agencies'* (ID20). Compounding this problem, results show that knowledge exchange processes and strategies were not clearly identified and planned for during the program's development, and as such, participants believed that there were insufficient resources to undertake engagement and knowledge exchange activities in a meaningful manner.

Finally, several participants also identified the geographic isolation of Ningaloo Marine Park and its local managers as a barrier to knowledge exchange (Table 1, Theme 2e). This was largely driven by the logistical and financial constraints that were associated with travelling to the region to have face to face engagement with the managers: *'The biggest barrier was that it was such an enormous distance to travel to get there … so the transaction cost of engaging deeply was enormous'* (ID17). Local managers also noted barriers to knowledge exchange that were associated with remoteness, such as slow internet speeds preventing them from sharing resources with scientists as email attachments, and searching and downloading scientific literature and program outputs.

### 3.3. Designing conservation research programs that facilitate knowledge exchange

Advice on how to design conservation research programs that actively facilitate knowledge exchange among conservation scientists and decision-makers resulted in three themes which also correspond to three stages of research programs; the development and design phase; the implementation phase; and the period following the conclusion of a research program. Of these, the design and development phase of conservation research was often identified by participants as the most important for ensuring the success of knowledge exchange, and therefore not surprisingly, was also the most frequently discussed (Table 1, Theme 3a).

In the design and development phase, the co-development of research questions was identified as a critical factor underpinning the success of knowledge exchange: '*… it cannot be hijacked by one agency …. if you want management outcomes it must be truly representative …. you have to have all of the different agencies and end-users, including traditional owners, at the table prioritising what needs to be done*' (ID20). As part of this, participants also stressed the importance of identifying and articulating all relevant stakeholders and end-users as early as possible, so as to incorporate all of their different values and interests. In addition, participants often

raised the need to identify a range of context-specific knowledge exchange strategies during the design phase of conservation research programs, and plan for their implementation (including budgeting) accordingly: *'Knowledge exchange processes need to be planned for and budgeted at the beginning, which doesn't often happen'* (ID5). The design phase should also include people with expertise and experience in knowledge exchange, as well as social scientists who can help to understand the social networks and patterns of influence among program participants: *'We should have understood the social networks and patterns of influence before we started … mapping the roles of the various individuals'* (ID19) *' … this would have helped to understand patterns of knowledge flow, and also what motivates different groups to engage'* (ID17). Finally, participants also emphasised that the design phase of conservation research programs should consider the legacy of the program, and how the knowledge will be maintained and kept up to date and used following the completion of the scientific activity.

To facilitate knowledge exchange and evidenced-based decision-making during the implementation of a conservation research program (Table 1, Theme 3b), participants identified three key requirements. These were the use of an intermediary, the co-production of knowledge, and a concerted effort on community engagement. Participants often identified the potential benefits of having a dedicated knowledge broker throughout the life of the program, who was solely responsible for building networks among the scientists and decision-makers and facilitating the exchange of knowledge among the groups: *'It would really help to have somebody, an intermediary, a knowledge broker, who can run the gamut between the scientists and managers and interpret things back and forth … '* (ID10). Results also show that to be most effective the intermediary should be embedded within the management agency, be politically astute, and have strong communication skills and the ability to cultivate expansive and productive social networks. Several participants noted that a critical factor underpinning the success of an intermediary will be the extent to which they can gain the trust of all relevant stakeholders, with participants noting the need for honest knowledge brokering: *'For most of my career I have worked at the interface of science and policy, and I've been on both sides of the fence, and I know that trust, objectivity and full disclosure are critical elements of knowledge brokering'* (ID13).

Participants also emphasised the need for participatory research approaches, and in particular, the co-production of knowledge to ensure knowledge exchange among scientists and decision-makers. As noted above, this should commence with the co-development of research questions among all relevant stakeholders, and should continue throughout the implementation of the research so that decision-makers actively participate in all stages of the scientific process: *'I see it as a partnership where we're doing the work together … it gives the managers a sense of ownership over the science and helps them to understand the science … which they can then pass onto their colleagues, and also the community and visitors to the region'* (ID6). Interviewees suggested that knowledge co-production will be most effective when scientists and decision-makers are co-located, and also highlighted the importance of having science teams embedded within decision-making agencies. Finally, to improve knowledge exchange among scientists and decision-makers during the implementation phase of conservation research programs, participants spoke of the need to focus on broader community engagement. While it was noted that this does not directly influence knowledge exchange processes *per se*, managers often discussed how community engagement in science can lead to the establishment of social licence and acceptance of management actions, thus empowering decision-makers to actually use the new knowledge to inform decision-making processes. To this end, participants identified the potential of citizen science programs, whereby members of the community actively participate in and lead scientific research programs, as a means of community engagement in conservation science.

Finally, strategies are also needed for the period following the completion of conservation research programs, to ensure that the new knowledge generated is successfully incorporated into decision-making (Table 1, Theme 3c). Specifically, the majority of decision-makers interviewed in this study described how to date, there have been limited opportunities to use new knowledge in relation to marine park management, for example, highlighting how the revision of Marine Park Management Plan only happens every 10 years. As such, they also identified the need for effective knowledge management systems within the decision-making agency, to ensure that when there is the opportunity to integrate knowledge into decision-making processes it is accessible: *' … because of the immense amounts of data that has been generated it needs to be findable, it needs to be accessible, it needs to be understandable'* (ID8). Interviewees suggested that this would be best achieved through the establishment of an archival database that could be searched using key words, accompanied by a GIS map whereby managers can search for knowledge geographically. It was also noted, however, that scientific knowledge can become outdated very quickly, and that there must be a mechanism to ensure that the database is maintained after the completion of the program. Similarly, the knowledge broker should remain active after the completion of the research, to continue to link the science to decision-making needs as they arise.

### 3.4. Core capacities to support knowledge exchange

The interview analysis identified three themes related to capacities and competencies needed to support knowledge exchange activities associated with conservation research programs: individual, institutional and financial capacities. Of these, individual capacities were raised most often (Table 1, Theme 4a), particularly the need for individuals with strong communication skills who have high levels of individual motivation to engage with others: *'Everyone involved in the program has to have the ability to talk to people, to be friendly, to be approachable and to be able to speak in plain English and not just science'* (ID18). Participants also identified the need for decision-makers to have a background in science as a critical capacity underpinning the success of knowledge exchange activities: *'Having someone with a strong scientific understanding directly involved in our day-to-day operations is a big step forward for us … it's not so much of a rubber stamp process when new research comes across our desk, it's a more informed and engaged process'* (ID1). This sentiment was also echoed by a number of scientists involved in the NRP: *'I really believe that if science is to make a useful contribution to decision-makers, then decision-makers must have a better understanding of the scientific method and issues relating to uncertainty'* (ID16). At the same time, participants identified the need for scientists to have a strong understanding of decision-making contexts and how to influence decision-making processes, as an individual core capacity required to facilitate knowledge exchange.

Participants identified a range of institutional capacities that must be developed to adequately support knowledge exchange activities (Table 1, Theme 4b). For the most part, these applied to both research organisations and decision-making agencies. For example there is a need to formally recognise knowledge exchange activities in job descriptions and reward knowledge exchange activities appropriately: *'We do try to engage with scientists, of course we do, but it's not officially recognised as part of our job description … I think it has to be, because it is a key part of being a manager, and a key part of ensuring we make management decisions based on the best*

*available science*' (ID8). Some capacities were specific to particular groups. For example, participants emphasised the need for research institutions to provide knowledge exchange training to scientists as formal courses in the tuition of early career researchers: *'The one thing missing in science education in universities around Australia is training in stakeholder engagement and knowledge exchange … it's not the same as science communication …. we need to teach scientists how to gain access to the right people and gain credibility with those people'* (ID13). Finally, participants recognised the need to build financial capacity to support knowledge exchange, both during and beyond the completion of the research program (Table 1, Theme 4c).

### 3.5. Key principles for designing conservation research

Based on a synthesis of the themes outlined above, a set of guiding principles, strategies and processes emerged that should guide the development and implementation of conservation research programs in the future to enhance the likelihood that conservation science will inform decision-making processes (Fig 1).

When commencing a new conservation-related research program, the first step of the design phase should be the identification and articulation of all relevant stakeholders via stakeholder mapping (Fig. 1, design phase). All stakeholders should then be invited into the design phase to co-develop the research questions to ensure they align with the research needs of the various groups. Results also highlight the importance of having experts in knowledge exchange included in the design phase of conservation research, and to identify, plan and articulate knowledge exchange processes for the life of the program, and ensure opportunities exist to review and adapt strategies as needed (Fig. 1, design phase). During the implementation phase of conservation research, it is critical that all stakeholders remain engaged in the research, which can be achieved via the implementation of participatory research approaches whereby managers actively participate in data collection, analysis and interpretation To complement this, however, an intermediary such as a knowledge broker should also be utilised to focus exclusively on enhancing knowledge exchange among the various program stakeholders (Fig. 1, implementation phase). For knowledge brokers to be most effective, they should be embedded within a management agency, have a strong understanding of science and decision-making cultures and contexts, have strong communication skills and the ability to cultivate expansive and productive social networks. Finally, following the completion of conservation research programs it is essential that knowledge is maintained in a manner that ensures that it is discoverable, accessible and understandable, and also updated as new knowledge comes to hand (Fig. 1, after completion phase).

To support these efforts a range of individual, institutional and financial capacities must be developed (Fig. 2). Individual capacities that can be improved include communication, networking, and a strong understanding of scientific and decision making contexts. Financial capacities include the obvious need for dedicated funding to support knowledge exchange beyond the lifetime of the primary research project. Although often overlooked when designing individual programs, developing the institutional capacity in terms of training, reward incentives for knowledge exchange and support for these activities is also critical (Fig. 2).

## 4. Discussion

Successfully responding to modern day conservation challenges will require improved knowledge exchange among scientists and decision-makers to enable learning and evidence-based decision-making (Fazey et al., 2013). To date, however, efforts to improve knowledge exchange have been hindered by a paucity of empirically-grounded guidance to help conservation scientists and practitioners design and implement research programs that actively facilitate knowledge exchange (Reed et al., 2014). This study addresses this gap by undertaking an in-depth evaluation of one conservation research program, the NRP, to identify the key barriers hindering knowledge exchange among conservation scientists and decision-makers, and strategies for overcoming these barriers. By gathering this information this study provides guidance for conservation scientists and decision-makers on how to undertake conservation research programs in the future that actively

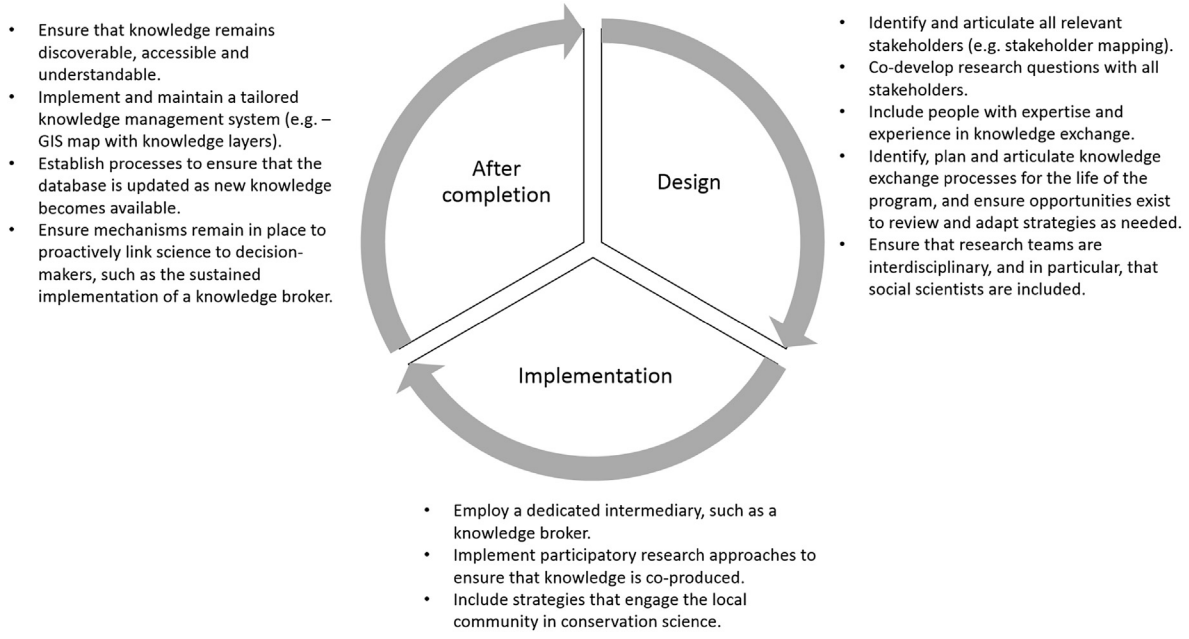


**Fig. 1.** Key principles in each of three research phases for improving knowledge exchange among conservation scientists and decision-makers.

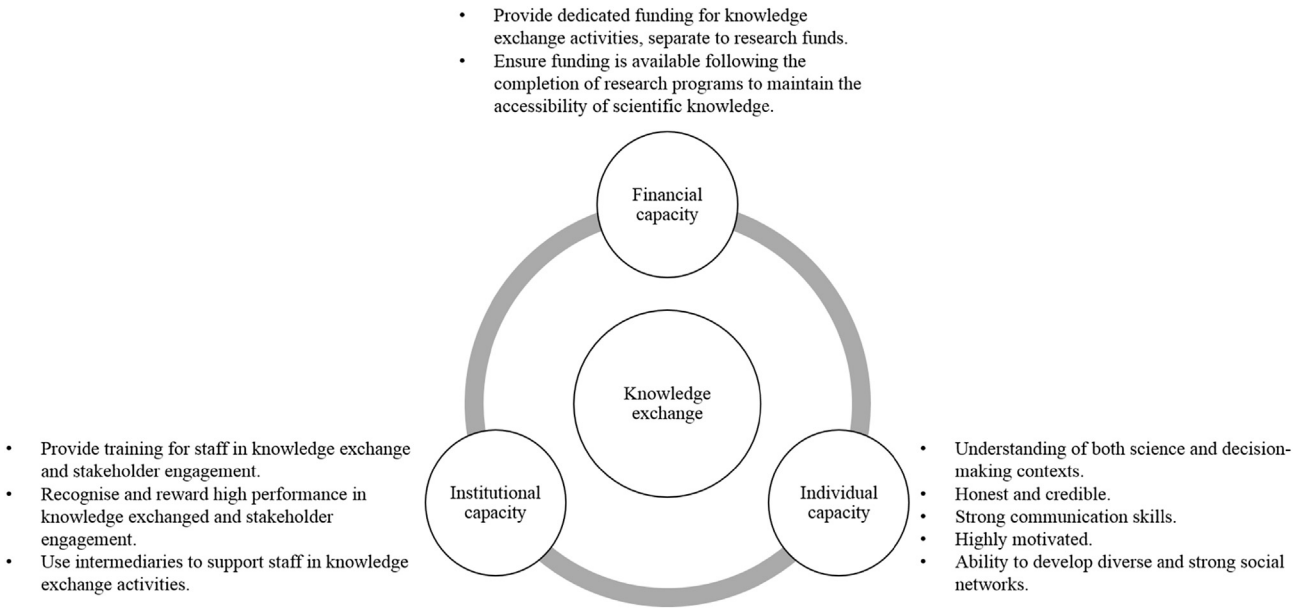


**Fig. 2.** Core capacities required to support and facilitate knowledge exchange among conservation scientists and decision-makers.

support knowledge exchange and evidence-based decision-making.

In terms of generating new information, as with many scientifically driven programs, the NRP delivered to this objective (Table 1, Theme 1a). However, participants stated that very little of this knowledge had been successfully exchanged with decision-makers or incorporated into decision-making processes. Rather, most participants outlined a range of barriers that had prevented knowledge exchange among scientists and decision-makers. The most significant barrier to knowledge exchange identified through this study was cultural differences between scientists and decision-makers (Table 1, Theme 2a). Cultural differences, as reported here, have been repeatedly identified as a primary barrier to knowledge exchange and evidence-based decision-making (e.g. - Kinzig, 2001; Briggs, 2006; Roux et al., 2006; Brown and Farrelly, 2009; Cvitanovic et al., 2013). For example, an extensive body of literature identifies the 'publish or perish' culture of science as a barrier to knowledge exchange, whereby scientists are driven and rewarded according to institutional incentives such as publication in peer-reviewed journals, which are less useful for decision-makers (e.g. - Jacobson et al., 2004; Shanley and López, 2009; Cvitanovic et al., 2015b). This practice leads to an inward-looking and self-serving scientific culture (Roux et al., 2006). In contrast, decision-makers are typically focused on day-to-day operations, and driven by a range of political, economic and social drivers that reflect broader societal issues (e.g. - Policansky, 1998). This results in decision-makers having limited capacity to engage sufficiently with science, perpetuating a culture in which science is not valued or used within decision-making processes.

Several institutional factors within decision-making agencies were also identified as key barriers that undermined the success of knowledge exchange activities (Table 1, Theme 2b). In particular, issues associated with leadership and hierarchical organisational structures were found to have adverse effects on knowledge exchange processes. The importance of strong leadership for tackling conservation challenges is well established in the scientific literature (e.g.- Dietz et al., 2004; Manolis et al., 2009). As reviewed by Black et al. (2011), this is because a leader's world view and management style influences the focus, operation, structure, policy, goal setting and decision-making processes within an organisation. Accordingly, when conservation managers do not feel adequately supported by leaders within their organisation for particular activities (in this case knowledge exchange), it can adversely affect an organisation and greatly reduce the results that are achieved (Seddon, 2003). Thus, to ensure the success of knowledge exchange strategies it is critical that leadership positions are occupied by individuals who establish clear agency mandates, adequately resource the implementation of the mandate, empower staff, and create a strong culture that values science (Jantarasami et al., 2010; Black et al., 2011; Cvitanovic et al., 2014b).

The inaccessibility of science to decision-makers emerged as a key barrier undermining knowledge exchange, particularly in terms of time lags between data collection and availability (Table 1, Theme 2c). This is reflected in previous assessments of science accessibility which have shown that, on average, it takes four years for conservation science to be published after the completion of data collection (Fazey et al., 2005). Such delayed access to science undermines the timely integration of knowledge into decision-making processes, as the knowledge may be out of date and less useful to decision-makers by the time it is made available (Linklater, 2003). Even when new scientific knowledge was available to decision-makers involved in the NRP, the results and their implications were not presented in a manner that was understandable by decision-makers, further undermining attempts at knowledge exchange (Fazey et al., 2005; Cvitanovic et al., 2014a).

Several factors and processes can enhance the effectiveness and efficiency of knowledge exchange activities at each phase of the research cycle (i.e. - design, implementation and after the completion of scientific activity, Fig 1), overcoming barriers to knowledge exchange and improving the likelihood that conservation science will be integrated into decision-making processes. Of these, the design phase of conservation research was widely regarded as the most important for ensuring the success of knowledge exchange activities (Table 1, Theme 3a), and in particular, results emphasise the importance of identifying and co-developing research questions with all relevant stakeholders. Indeed, not engaging all interested stakeholders during the design phase of conservation research has the potential to marginalise

important groups, bias results and jeopardise the long-term viability and support for the process (Reed et al., 2009; Reed and Curzon, 2015). To this end it is critical that stakeholder analysis (also referred to as stakeholder mapping) is undertaken as part of the design phase of conservation research, to identify all relevant stakeholders and understand the relationships and patterns of knowledge flow among them (Crona and Bodin, 2006; Bodin and Crona, 2009). Several descriptive, normative and instrumental approaches to stakeholder analysis are available for this purpose (reviewed by Reed et al., 2009). Of these, social network analysis is particularly useful, given that it allows for the identification of stakeholders who should be engaged in the processes, and allows researchers to identify the role and influence of different stakeholders according to their position within the network (e.g. - Prell et al., 2009; Syme et al., 2012; Mills et al., 2014; Cunningham et al., 2015).

Knowledge exchange among conservation scientists and decision-makers can be enhanced by utilising participatory research approaches during the implementation phase of research (Table 1, Theme 3b; Fig 1). Participatory research approaches such as knowledge co-production actively engages decision-makers and other stakeholders in all aspects of scientific research including design, implementation, analysis and interpretation (reviewed in Cvitanovic et al., 2015a). This leads to decision-makers having a stronger understanding of the research content, as well as developing a strong sense of ownership over the research, which they can then communicate more broadly within their organisation (reviewed by Reed, 2008). Furthermore, participatory research approaches are believed to increase the extent to which decision-makers will perceive science to be salient, credible and legitimate, all key factors that influence the extent to which science is incorporated into decision-making processes (Cash and Moser, 2000; Cash et al., 2003). While participatory research approaches can occur in a number of ways (Van Kerkhoff and Lebel, 2006), the most widely advocated is knowledge co-production, whereby decision-makers actively participate in every aspect of the scientific process, from concept design to data collection, analysis and interpretation (Van Kerkhoff and Lebel, 2015). It is important to note, however, that while such processes improve knowledge exchange among scientists and decision-makers they can also be resource intensive, and thus require adequate financial and institutional support to ensure their success (Fig 2) (Cvitanovic et al., 2015a).

To complement participatory research approaches and further build capacity for improved knowledge exchange among scientists and decision-makers during the implementation phase of conservation research (Fig 1), the use of an intermediary such as a knowledge broker, can be useful. While knowledge brokers are conceptualised and operationalised differently in various sectors (e.g.- Bornbaun et al., 2015; Reinecke, 2015), the key feature of such a role is to facilitate the exchange of knowledge between and among various stakeholders (Dobbins et al., 2009). In doing so knowledge brokers are believed to facilitate organisational change by removing barriers to knowledge exchange and promoting a culture that values the use of the best available science in policy and practice, and influencing science so that it is tailored to the needs of decision-makers (Michaels, 2009; Meyer, 2010). As such formal knowledge broker roles should be considered to increase the impact and uptake of conservation science.

To maximise knowledge exchange among conservation researchers and decision-makers it is also important to ensure that new knowledge is effectively managed following the completion of research programs (Table 1, Theme 3c). In this regard knowledge management is defined as the process of storing and maintaining knowledge, so that it can be effectively drawn upon to inform decision-making processes as needed (Alavi and Leidner, 2001). As reviewed by Reed et al. (2013), scientific knowledge can be stored and managed through a variety of mechanisms, ranging from web-based platforms to mimicry from person to person. Irrespective of the approach taken, to be effective knowledge management systems must include mechanisms to ensure that knowledge is easily discoverable, accessible and understandable to decision-makers. At the same time, knowledge management systems must be maintained and updated as new research is completed, with mechanisms in place to ensure that this new information is adequately and proactively brokered to decision-makers (Reed et al., 2009). Again, this could be achieved through a knowledge broker, and thus this study highlights the importance of having knowledge brokers included as part of research programs, and as part of long-term organisational strategies following the completion of research programs.

The need for an effective knowledge management system following the completion of conservation research programs was often discussed within the context of the limited opportunities to integrate new knowledge into decision-making processes (Fig. 1). As an example, the Management Plan for the Ningaloo Marine Park is only updated every ten years, so research needs to be held in some discoverable and accessible form until it can be used at the appropriate time. While this was not identified as a barrier undermining knowledge exchange among conservation scientists and decision-makers as such, long gaps between policy updates can undermine the recognition and value of knowledge exchange, and limit the potential for evidence-based decision-making and the implementation of adaptive governance arrangements (Österblom and Folke, 2013; Chaffin et al., 2014). This is because a defining feature of adaptive governance is the ability to review and modify decisions as new information becomes available (Evans et al., 2011). This can only occur if decision-making processes and structures are responsive to new information (Arnold and Gunderson, 2013).

While this study identified a range of critical factors and processes that will improve knowledge exchange among conservation scientists and decision-makers, they must be underpinned by the development of a range of core capacities for maximum impact. In this regard, capacity is defined as both the capability to act, and the competencies required to do so (Franks, 1999). When applied to knowledge exchange, core capacities are those required to create, access, interpret, and apply scientific knowledge (Van Kerkhoff and Lebel, 2015). Based on our comprehensive evaluation of the NRP it is evident that core capacities must be developed at three levels to support effective and efficient knowledge exchange: individual, institutional and financial (Fig 2). For example at the individual level, knowledge exchange processes can be enhanced by ensuring that all participants have strong communication skills and high levels of motivation to actively participate in stakeholder engagement activities. These traits should form the basis of selecting individuals to take part in conservation research programs, and where individual capacities are lacking, training should be provided to build capacity (González, 2001; Sambunjak et al., 2006). Similarly at the institutional level there is a need to build capacity using innovations that legitimise knowledge exchange activities as core business for staff (be they researchers or decision-makers). This must include institutions formally recognising and rewarding achievements in knowledge exchange, thus creating a culture that promotes collaboration and knowledge exchange (Cvitanovic et al., 2015a; Lacey et al., 2015). Finally, for all of this to occur it is critical that knowledge exchange activities are adequately financed during the research program, and after its completion to ensure successful knowledge management.

## 5. Conclusion

This study is among the first to empirically evaluate knowledge exchange activities associated with conservation research programs. Despite perceptions of increased awareness among the conservation community regarding the need for improved knowledge exchange among the groups, an implementation gap remains. Barriers inhibiting knowledge exchange reported here reflect those previously reported, including cultural differences among scientists and decision-makers, a range of institutional barriers such as problems associated with inadequate leadership, and the inaccessibility of primary science to decision-makers. To overcome these barriers, however, this study offers empirically-grounded guidance that should be implemented as part of future conservation research programs. In particular, future research programs should utilise stakeholder mapping processes to identify and include all relevant stakeholders within the research program, ensure that research questions are co-developed so as to match research outcomes with needs, implement participatory research approaches and knowledge brokers to enhance knowledge exchange during the implementation of conservation research, and ensure that appropriate and long-term knowledge management systems are established. To support these efforts a range of individual, institutional and financial capacities must be developed. While the implementation of some of the structures outlined here are large in scale and potentially costly, doing so will improve knowledge exchange among conservation scientists and decision-makers, thus building capacity for evidence-based decision-making and increasing society's ability to respond to modern day conservation challenges.

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## Appendix A. Interview schedule

*Introductory questions*

1. What is your role in [your organisation]?
2. What was your role in the Ningaloo Research Program?
   Prompt: Duration? Involvement (project leader, researcher, etc)

*Background to interviewee's perceptions of the NRP*

3. What is your understanding of the purpose and objectives of the NRP?

*Background to interviewee's understanding of the research/ implementation knowledge exchange process*

This project is interested in the process of knowledge exchange. Knowledge exchange describes the interchange of knowledge between "scientific" producers and research users, and encompasses all facets of knowledge production, sharing, storage, mobilization, translation and use.

4. What would successful knowledge exchange look like in relation to your work?
   Prompt: What benefits (e.g.- environmental, societal, departmental etc) would you expect as a result of successful knowledge exchange?
5. Can you please explain your understanding of the knowledge exchange strategy, if any, used for the NRP?

*Experience of NRP outcomes*

6. Based on your experience of the NRP, can you please outline:
   6.1 To what the extent it delivered new knowledge for informing decision-making processes?
   6.2 any other benefits that flowed from the programs?
   6.3 Where there any non-beneficial, or detrimental, outcomes of the NRP?
7. Based on your experience, has the new knowledge generated through the NRP being successfully exchanged with decision-makers and used to inform decision-making processes in relation to the Ningaloo Marine Park.?
   7.1a Can you describe to me a specific example of when new knowledge generated through the NRP was used to inform a decision, and the factors that led to this success?

*Factors influencing knowledge exchange*

8. What factors contributed, either positively or negatively, to knowledge exchange?
9. What, if any, barriers did you experience that prevented efficient and effective knowledge exchange, and how did you try to overcome these barriers?

*Improvements to knowledge exchange*

10. Based on your experience in the NRP, how should knowledge exchange strategies and processes be designed in the future to enhance the effectiveness of knowledge exchange?
11. Based on your experience in the NRP, what capacities/resources do you think are required to enable more effective knowledge exchange strategies in the future?
    Prompts: i.e.- the individual, organisational, social, political, material, technical, practical and financial elements required to reach the desired outcome.

*Conclusion*

13. Now that we have completed the formal component of the interview, are there other important issues that were not covered by our questions, or other relevant insights that you would like to share based on you experience in the NRP?
14. At the completion of this project we would like to produce guidance that can help others to learn from your experiences. How do you think we could communicate our findings to your organisation and your stakeholders most effectively?
15. To ensure that we can adequately assess the effectiveness of knowledge exchange strategies implemented as part of the NRP we want to interview a representative cross section of

the relevant stakeholders. Can you think of anyone else that we should interview for this project?

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