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Designing environmental research for impact

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HIGHLIGHTS

- This paper explores how environmental research can be more influential.
- Transdisciplinary research means researchers working with end users.
- Funders, researchers and end users have a shared stake in successful outcomes.
- Research is most likely to be influential when all three groups have shared goals.
- Mutual trust, continuity of personnel and adaptive capacity are key success factors.

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ABSTRACT

Transdisciplinary research, involving close collaboration between researchers and the users of research, has been a feature of environmental problem solving for several decades, often spurred by the need to find negotiated outcomes to intractable problems. In 2005, the Australian government allocated funding to its environment portfolio for public good research, which resulted in consecutive four-year programmes (Commonwealth Environmental Research Facilities, National Environmental Research Program). In April 2014, representatives of the funders, researchers and research users associated with these programmes met to reflect on eight years of experience with these collaborative research models.

This structured reflection concluded that successful multi-institutional transdisciplinary research is necessarily a joint enterprise between funding agencies, researchers and the end users of research. The design and governance of research programmes need to explicitly recognise shared accountabilities among the participants, while respecting the different perspectives of each group. Experience shows that traditional incentive systems for academic researchers, current trends in public sector management, and loose organisation of many end users, work against sustained transdisciplinary research on intractable problems, which require continuity and adaptive learning by all three parties. The likelihood of research influencing and improving environmental policy and management is maximised when researchers, funders and research users have shared goals; there is sufficient continuity of personnel to build trust and sustain dialogue throughout the research process from issue scoping to application of findings; and there is sufficient flexibility in the funding, structure and operation of transdisciplinary research initiatives to enable the enterprise to assimilate and respond to new knowledge and situations.

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1. Introduction

Human society faces a number of 'grand challenges', several of which arise from the relationship between people and the environment. These include climate change adaptation and mitigation, food security,

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Table 1
A framework to guide co-reflection on progress in transdisciplinary research programmes that incorporates the accountabilities of funders, researchers and end users (after Roux et al., 2010).

Functional domain	Accountability indicators
Funders of research	Strategic planning and leadership Continuity and scientific competency Discourse between funders, providers and users to ensure effective programme goals and model Flexibility to adjust programme model and goals to meet research provider and user needs
Providers of research	Adaptive learning Professionalism Knowledge sharing Relevance to end-user needs Capacity building Research excellence
Users of research	Capacity for adoption Adaptive decision-making and policy revision Continuity of personnel Co-location of personnel Capacity to build upon emerging research

energy and water security, habitat loss and species extinctions, pollution, and the spread of weeds, pests and diseases.

These and other ‘wicked problems’ (Brown et al., 2010) are characterised by technical complexity and often uncertainty, large scales in space and time, a mix of social, economic and biophysical drivers, abundant but disparate and heterogeneous data, and contested issues among diverse stakeholders. The nature of such contest is itself important: it may be rooted in conflict over values and norms, and/or uncertainty in the data. Notwithstanding complexity, uncertainty, risk and conflict, on such issues there is nevertheless typically a need for governments, industries and communities to make a choice, reflected in decisions and actions. Such choices are often negotiated, often messy rather than clear-cut, and for most environmental issues the choice to do nothing (whether made actively or by default) also has environmental consequences.

A key response to such environmental challenges is to invest in applied research, which the Australian Bureau of Statistics (1998) defines as ‘work undertaken primarily to acquire new knowledge with a specific application in view’. The nature of these challenges is such that they can rarely be comprehended satisfactorily within a single scientific discipline, or indeed by science alone. There is a significant literature on the conceptual challenges associated with multi-, inter- and trans-disciplinary research (Fry, 2001; Klein, 2008; Gibbons et al., 2008; Bammer, 2013), and on the imperative for new ways of organising research – e.g. ‘Mode 2’ research and ‘Post-normal science’ (Funtowicz and Ravetz, 1993). Less has been published about the practice of working with end users to design and organise multi-institutional environmental research to tackle large scale, long-term environmental problems, based on analyses of current and past experience (Campbell and Schofield, 2007; Tress et al., 2005a, 2005b).

Australia has invested significantly over the last twenty years in organising applied research collaborations at national scale, including the Cooperative Research Centres programme (Allens, 2012), Rural Research and Development Corporations (Productivity Commission, 2011), and Centres of Excellence funded by the Australian Research Council and the National Climate Change Adaptation Research Facility (NCCARF, 2014).

This paper briefly reviews what we mean by transdisciplinary research, then discusses the findings of a participative, ‘structured reflection’ involving researchers, funders and end users of successive national environmental research initiatives in Australia, adapting an analytical framework developed by Roux et al. (2010).

2. Transdisciplinary research

Roux et al. (2010) propose a “framework for participative reflection on the accomplishment of transdisciplinary research programs”. They distinguish between post-normal science (Funtowicz and Ravetz, 1993; Francis and Goodman, 2010), sustainability science (Clark and Dickson, 2003; Burns and Weaver, 2008), and interdisciplinary studies (Newell, 2001; Repko, 2008), while noting ‘considerable overlaps of purpose’ between these approaches and the key point that all purport to complement, rather than replace traditional disciplinary research. Transdisciplinary studies incorporate elements of all these approaches in applying insights and tools from different disciplines, explicitly embracing complexity and uncertainty, acknowledging multi-stakeholder perceptions and values, in addressing problems that are ‘user inspired and context driven’ (Roux et al., 2010). A key feature of transdisciplinary research thus defined is the engagement of non-scientist stakeholders – in particular the end users of research – in the research enterprise (Roux et al., 2010):

“A key characteristic of transdisciplinary research is that the domains of science, management, planning, policy and practice are interactively involved in issue framing, knowledge production and knowledge application.”

Accordingly, Roux et al. (2010) suggest that there are three key groups of stakeholders in transdisciplinary research: researchers, end users of research, and funders of research. While all three groups may have shared broad goals to *acquire new knowledge with a specific application in view* they are likely to have different perspectives on those goals and how to achieve them, and to define success in different ways. Roux et al. (2010) propose a framework that sets out different accountabilities for the three ‘functional domains’ of funders, researchers and end users, as in Table 1 below.

More detail explaining each of these accountabilities is set out in Roux et al. (2010) who caution that these are not proposed as definitive or comprehensive, but to serve as a departure point from which this framework could be modified in the context of a specific research initiative.

3. Australia's national environmental research programmes

The Roux et al. (2010) framework was seen to be ideally suited for use as an analytical lens to distill lessons for the design and management of collaborative, multi-institutional applied environmental research from the experience of national environmental research programmes sponsored by the Australian government.

The key process in the application of the Roux et al. (2010) framework was a ‘structured reflection’ workshop such as the one involving the authors of this paper in April 2014. The workshop participants between them had well over one hundred person years of experience in leading and/or funding multi-institutional, transdisciplinary research programmes, with total investment exceeding \$500 m. The workshop was further informed by an on-line survey of 500 participants with experience in the programmes. Each respondent was asked to self-identify as a researcher, research funder or end-user/stakeholder. A response rate of around 9% was obtained, of whom 57% claimed to be researchers, 11% research funders, and 32% were end-users and/or stakeholders. Several respondents identified with more than one role.

The two research programmes analysed in depth at the workshop were the Commonwealth Environmental Research Facilities (CERF) programme, which was initiated by the Australian government environment ministry in 2006, and subsequently evolved into the National Environmental Research Program (NERP) from 2010. The \$160 m CERF programme was evaluated by Urbis (2010). The \$154 m NERP programme is described by DEWHA (2010) and was evaluated by Spencer et al. (2014). Both programmes were designed to meet the perceived

knowledge needs of the environment portfolio, and to tackle issues that were not being adequately addressed by research investments through other government programmes.

The CERF programme commenced with a national call for research proposals against a programme prospectus. Well over one hundred proposals were evaluated on merit by an independent, expert reference group that recommended a suite of investments to the Minister for the Environment, including individual research projects, 'hubs' (clusters of research projects focused on particular problems/themes/ecosystems) and fellowships. The NERP programme drew on the experience and the evaluation of the CERF programme (Urbis, 2010) in having a competitive national Expression of Interest process against broad research priorities, but then focusing its investment primarily around five research hubs, all of which evolved out of successful antecedents in the CERF programme (Appendix A).

As of March 2014, almost 560 researchers from 53 organisations and many more end users had participated in NERP projects, many of whom were also involved in the preceding CERF programme. Unfortunately, there was not a seamless transition from CERF to NERP, but rather a significant hiatus in funding during which some researchers who had been funded through CERF moved on to other roles. In the transition from CERF to NERP, the federal environment department sharpened its focus to concentrate on biodiversity conservation and management, and framed itself more explicitly as the key client and end-user of the outputs of the programme. The NERP programme was thus expected to inform policy development and programme implementation within the federal environment department first and foremost. However, the programme was supported by an equivalent level of co-investment from other research users and partners, including other departments, governments (at state and local levels), industries and communities, who also expected useful outputs from the research relevant to their interests.

The ability of the five NERP hubs (Appendix A) to respond to the needs and interests of their research users meant that they evolved subtly different structures and *modus operandi*. Three had a strong and extensive geographic focus: the Tropical Ecosystems hub focused on the Great Barrier Reef, its rainforest hinterland and the Torres Strait; the Marine Biodiversity Hub focused on Australia's marine territory; and the Northern Australian Biodiversity hub focused on Northern Australian aquatic and terrestrial systems. These foci largely determined their research users and stakeholder groups, and resulted in a combination of bottom up self-organisation around specific research issues and top down coordination to resource and deliver large, complex research programmes. The Environmental Decisions hub worked in partnership with a wide range of research users in the public and private sectors across the country, identifying discrete research topics through focused workshops after which small teams worked with end users on projects of varying duration from several months to several years. The Landscapes and Policy hub identified several regions as case studies, with biophysical and social researchers working in interdependent teams on questions defined by the management agencies in each region.

Aligned with a general trend over the past twenty years for increased participation across all sectors in environmental management (Holley, 2010), the environment department outlined five key design parameters for strengthening links between researchers and policy makers (Box 1).

The five current NERP hubs now constitute a considerable body of experience and expertise in multi-institutional, transdisciplinary research collaborations focused on contemporary challenges in environmental science, policy and management. All NERP hub directors, plus senior representatives of funders and end users, participated in the ACEAS workshop.

Lessons emerging from each of the hubs and the insights of their directors are elaborated further below. While the NERP hubs were all selected against the same national prospectus and funded by the same government agency against the same overall objectives, guidelines and accountability measures, it is notable that each developed in quite different ways. All now have distinct and markedly different identities

Box 1

Design parameters for the NERP programme to improve linkages between research and policy.

Excerpt from DIISRTE (2012).

NERP builds on the Commonwealth's experience in implementing and evaluating the previous Commonwealth Environment Research Facilities programme, and includes increased focus on mechanisms to ensure improved delivery to the end-users of funded research, particularly in government for evidence-based policy. In support of this objective, the programme reflects best practice principles for strengthening the links and alignment between research and the needs of policy makers:

- *involving policy makers in the framing of research questions:* NERP programme guidelines and research priorities are based upon consultation across the department, with a selection panel involving both researchers and departmental representatives then working through a two-stage process to allow for the further refinement of proposals.
- *specific focus on knowledge brokering and translation:* programme guidelines require that 10% of the funding for each hub must be devoted to communication and knowledge brokering activities – the programme also acknowledges that effective translation requires integration – across research disciplines and of new and existing knowledge.
- *facilitating access to research:* in addition to other communication efforts, all NERP-funded research outputs must be made freely and publicly available to allow their use by a broader range of decision-makers.
- *enhancing mutual understanding:* the programme also supports enhanced two-way engagement through mechanisms such as the identification of departmental end-users and contact officers for each hub, short-term secondments for researchers into the department and the 'pairing' of researchers and policy staff.
- *innovation in evaluation:* the NERP monitoring and evaluation strategy requires regular reporting on the usefulness of research in policy, with a mix of quantitative and qualitative measures employed.

Common challenges of linking research and policy remain, such as differing timelines and time pressures, and particularly the reward structures within which research and policy staff work, which often do not explicitly value the types of activity outlined above.

and *modus operandi*, yet the recent evaluation found each to be effective against both hub and programme level objectives. This suggests that there is no single 'magic bullet' formula for designing a successful collaborative applied environmental research programme. Rather, programme design, management structure and research practice should respond to the specific ecosystem/issue, mix of stakeholders and end users and the nature of their knowledge needs, cognizant of the history of research investment in that context.

Acknowledging the importance of context in shaping local responses, we nevertheless contend that principles of good applied environmental research practice emerge across all hubs. The following section attempts to elucidate these using the framework proposed by Roux et al. (2010), focusing on the five NERP hubs that originated in the CERF programme, summarised in Appendix A.

4. The relative accountabilities of researchers, funders and end users in transdisciplinary research programmes

In using the Roux et al. (2010) accountabilities as a lens through which to reflect on the experiences and achievements of the five hubs,

we involved a mix of researchers, funders and end users, both in the survey and the workshop. As suggested by Roux et al., we also monitored the utility of the framework during this reflection, and identified potential improvements.

Roux et al. (2010) cluster the accountabilities according to the functional domain (funders, researchers, end users) primarily responsible for their realisation. This implies that there could be shared accountabilities across domains, but this is not the impression conveyed (Table 1). We contend that multi-institutional, transdisciplinary research is a shared enterprise across funders, researchers and end users. All three domains have important roles to play, and most of these are shared responsibilities. The ultimate performance measure for such research is the generation of useful and relevant new knowledge that is applied by end users, resulting in a net environmental benefit that exceeds the cost of the research. It is very difficult for this to be realised, and it is not genuinely transdisciplinary research if any of the three domains is disengaged or discharges their responsibilities poorly.

Reflecting the conceptual framework of a shared enterprise, at the workshop we assigned a simple 3, 2 or 1 score to the degree of responsibility a given domain has for a given accountability (with 3 being most important), and we also modified the Roux et al. (2010) accountabilities slightly to better fit the NERP context, splitting some, combining others and deleting 'co-location'. The consensus view of the researchers, funders and end users involved in the April 2014 workshop produced a modified version of the Roux et al. (2010) framework.

These weighted accountabilities are illustrated in Fig. 1, enabling a visual comparison across the three domains.

The accountabilities seen as important for all three groups were leadership, engagement and discourse. All participants in collaborative transdisciplinary research need to demonstrate leadership and to remain engaged and actively communicating throughout the research process. Successful leadership and engagement require that each domain is able to understand and explain its own needs and potentials in ways that can be related to the needs and/or potentials of other domains.

The leaders of NERP-funded research hubs felt that it is important that funding agencies maintain sufficient continuity in staffing to be intelligent purchasers, able to 'take the long view' and undertake high quality strategic planning and adaptive management at a research programme level – responding to changing circumstances and priorities as necessary, but no more than necessary. Research funders need competent project management systems, extending to management of data, information and the knowledge 'legacy' from concluding research programmes. They need sufficient scientific capacity to be able to evaluate research proposals and to compare the track records of competing research providers, but not to the extent of second-guessing researchers once programmes and projects are contracted.

Researchers' accountabilities emphasise scientific competence, relevance, willingness to engage in two-way knowledge sharing and to respond to the needs of end users, competent project management and underpinning the quality of their research through publishing in strong journals, in addition to communication designed to be meaningful for end users.

The accountabilities for research end users underscore their willingness to engage in the research process to the extent necessary to maximise the chances of research outputs being fit for purpose, meeting research user knowledge needs and able to be implemented in their real world in industry, government or the community. This requires end users to have sufficient organisational research capacity and scientific competence to be able to engage effectively with researchers in problem definition and/or co-design of the research, which in turn requires continuity in personnel engaged in the research process.

The ultimate performance measure for such research investments is the extent to which programme outputs are adopted, and the resulting environmental benefit. The capacity to interrogate, adapt and utilise research outputs, and their ability to engage in adaptive learning and decision-making as new knowledge emerges, are crucial accountabilities for end users.

5. Discussion

The experience of the NERP hubs confirms that in successful transdisciplinary research programmes, research end users are not passive recipients of knowledge products arising from a linear process conceived by researchers and/or funders and implemented by researchers. Rather, it is essential that they work collaboratively with funders and researchers to define the problem and scope knowledge needs, work out approaches to tackle that problem, and then interact with researchers during the active inquiry phase of the programme so that researchers develop as deep an understanding as possible of the end users' context, why their research is important, and how their results will be used. Some problems will require more effort from the end user in defining questions, than from researchers in responding to them.

The shared experiences spanning the implementation of both the CERF and NERP models suggests that all participants' understanding of knowledge gaps evolves as collaborative applied research programmes unfold, which is why accountabilities such as engagement and discourse are important and continuity is critical for all three groups.

A design feature of the CERF programme that was seen as very successful and consequently built into the NERP programme (Box 1), was the requirement that each hub invest at least 10% of its budget in knowledge brokering and communication activities. Knowledge brokers are professional intermediaries (people or organisations) who facilitate knowledge exchange and sharing between researchers and practitioners. Knowledge brokering emerged in the public health sector (CHSRF, 2003) and is now applied in diverse ways in multiple sectors (Bielak et al., 2008; Michaels, 2009). Some NERP hubs have knowledge brokers embedded with end users, others with researchers, but all have explicit and significant investments in people and processes designed to ensure that end users are engaged in the research, and that research outputs are tailored to meet the needs of end users. While transaction costs may be high, the CERF and NERP experience is that direct, face-to-face interaction between researchers and end users is the most effective.

Knowledge brokering is situated along a spectrum of knowledge processes from conventional, linear dissemination of information (science communication) on the left hand side, through intermediary and brokering strategies in the middle, to co-production of knowledge, social learning and more systemic innovation (Fig. 2). A characteristic of knowledge brokering is that knowledge is provided at the time and in the form required by the end user rather than those most convenient to the researcher.

In some contexts, these knowledge intermediary processes may begin where the research stops, to improve uptake of research results and amplify research impact. In other contexts however – for example the complex, multi-dimensional and multi-stakeholder problems being addressed by the CERF and NERP hubs – brokering processes between the producers and users of knowledge (who may overlap to a significant degree) are seen to greatly enhance programme efficacy, particularly if undertaken *before* research is initiated, to refine research questions, influence methodologies, determine an appropriate form of delivery, and ensure that intended end-users have a degree of ownership of research outputs. In the context of the Australian environment, this is particularly relevant to respectful engagement with Indigenous Traditional Owners of Country. In such contexts, scientific inquiry may not be the only or even the most appropriate mode of knowledge production. Local, tacit, experiential and other forms of knowledge can emerge through various types of inquiry.

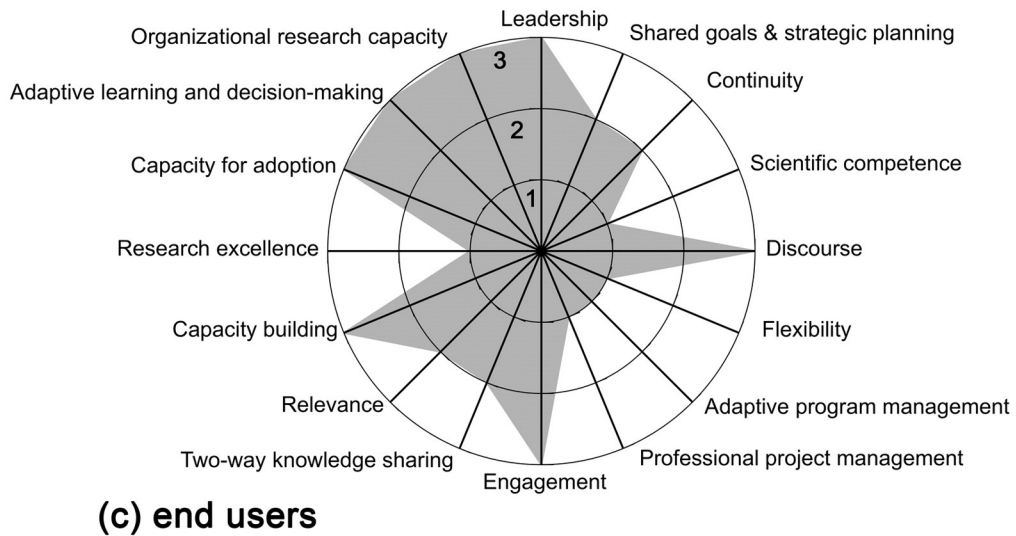
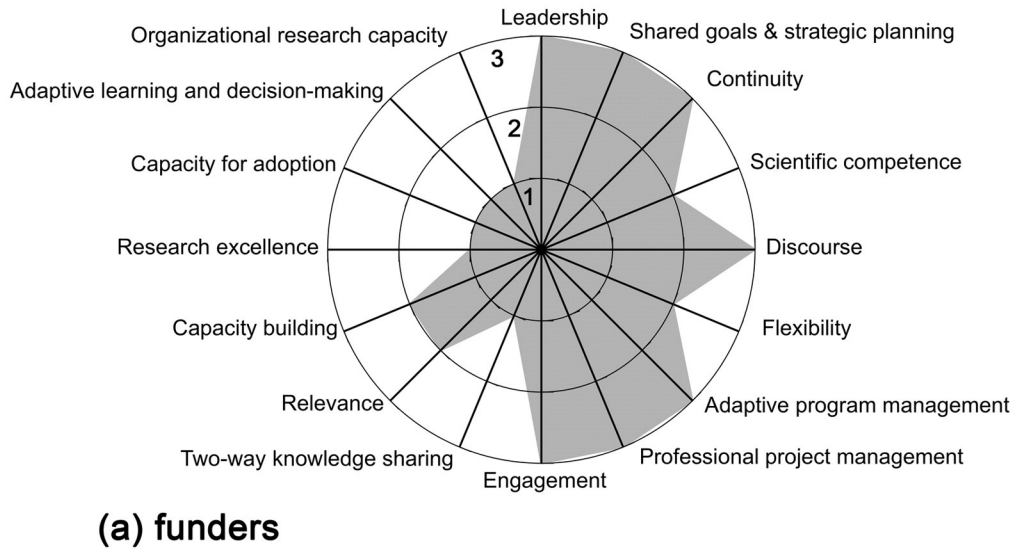


Fig. 1. Weighted accountabilities of (a) funders, (b) researchers and (c) end users in transdisciplinary research programmes.

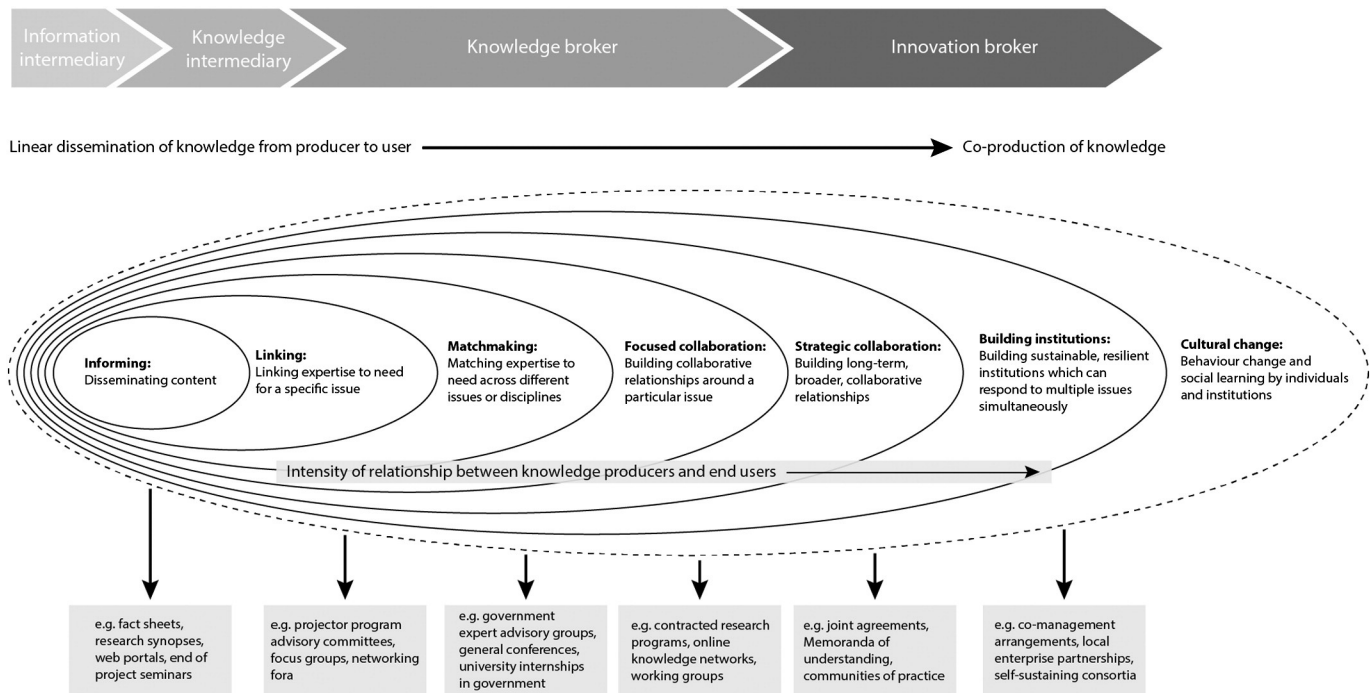


Fig. 2. Knowledge roles and functions from information dissemination to social learning. After Michaels (2009).

Of course useful research outcomes can and do occur without knowledge brokering, but they involve a greater element of chance which can and should be avoided, especially in times of constrained research funding and greater emphasis on accountability. It is doubtful that an organisation or research programme can jump to sophisticated knowledge intermediary processes (the right hand side of Fig. 2) without being competent at the basics of science communication: the ability to pick up research highlights early and present them well; good web interface and search capabilities; effective media and event strategies; and the ability to synthesize research outputs in attractive ways targeted to the knowledge needs of intended audiences. This requires dedicated resources, recognised in the CERF–NERP requirement to allocate at least 10% of budget to communication and knowledge brokering processes.

In designing transdisciplinary, multi-institutional environmental research programmes for impact, we need to understand the knowledge system we are seeking to influence. This means more than researchers' understanding their market, which is weakest with the Indigenous sector. Our key point, exemplified by the experience of the CERF and NERP hubs, is that such research is a shared enterprise between researchers, funders and end users, built on a platform of shared goals and social capital across these three functional domains.

Fig. 1 illustrates that continuity is an important attribute for all three groups. With sufficient continuity of personnel across the collaboration, elements of social capital such as trust and reciprocity become increasingly valuable as collaborations evolve and mature. Extended interaction over a number of years bridges the cultural differences between the different worlds of researchers and end users, it helps researchers to understand the needs of end users, it makes it easier for end users to challenge researchers and to interrogate research findings more freely, and it gives funders more confidence to invest in possibly riskier, less well-defined or more adaptive projects in a spirit of co-learning. The latter is facilitated when the funding body is also an end user, as the Australian Department of the Environment was with respect to the CERF and NERP programmes.

It is now all too common in Australia for research programmes to be funded for four years or less, which makes it difficult to sustain continuity of personnel and to build social capital (familiarity, respect, trust, reciprocity) between funders, researchers and end users. So the fact that five CERF hubs were successful in a national competitive funding round and hence became NERP hubs was very important in the evolution – and we would argue the success – of this overall investment.

The scale and complexity of 'wicked' environmental problems require both a transdisciplinary approach and sustained effort. Within the Tropical Ecosystems' NERP Hub, several research projects required at least ten years of sustained work to be useful, for example: (a) problems that require temporal data to track the response of an ecosystem after a management intervention such as rezoning or an extreme weather event; and (b) complex problems such as coastal water quality that have been attacked in bite-size (i.e. fundable) portions.

However it is important to note that continuity of funding for five hubs from CERF to NERP was by no means deliberate or guaranteed. In fact there was a funding gap between CERF and NERP, during which many CERF-funded researchers on short-term contracts moved on to other roles, thus undermining staff continuity and hub cohesion in the transition to NERP. Both the CERF and NERP programmes began with competitive funding processes, subject to normal Commonwealth procurement rules around contestability and competitive neutrality (DoF, 2014). Under such rules, against a background of three-year electoral cycles and budget processes, designing and sustaining long-term transdisciplinary research investments are inherently difficult. Two CERF hubs that were seen by the Department as being highly relevant and effective (focused on taxonomy and marine mammals), were not funded under NERP, due to revised government priorities for the programme and alternative funding sources.

The reviews of the CERF (Urbis, 2010) and NERP (Spencer et al., 2014) programmes revealed that the hubs' flexibility and responsiveness to identify research topics in detail with their research users enabled them to address environmental issues in their specific contexts,

at the appropriate scales and with objectives relevant to research users. Importantly, funding contracts with most of the NERP hubs were signed before all research projects were designed and specified in detail. Whether deliberate or not, the flexibility allowed to these NERP hubs in terms of refining research methods and detailed research programmes and projects in response to end user needs, turned out to be one of the strengths of the programme. Stakeholders and research users had a meaningful opportunity to influence the research direction and allocation of funds once the hubs became real and people were seriously engaged, rather than 'joining in' to established research projects after they had already been designed and funds already committed. As well as improving the relevance and impact of research outputs for users, in the opinion of the manager of the CERF and NERP programmes within the Department of the Environment, this ability to be flexible and responsive 'contributed to a positive cultural change to problem solving between researchers and the Environment Portfolio'.

Where research programmes were specified in detail and contracted as such from the outset, subsequent lack of flexibility became a problem as it constrained meaningful consultation with end users, which was especially problematic for Indigenous interests.

Political scientist **Brian Head (2008)** argues that in modern pluralist democracies, the response to any given policy problem is ultimately informed by the interplay between three distinctly different types of knowledge and evidence, as illustrated in Fig. 3.

In this formulation, scientific research is one 'lens' through which Ministers and their advisers seek to understand an issue, weighed up against political judgement and the organisational knowledge, corporate memory and professional practices of relevant agencies. Each lens has a distinctive epistemology – in effect polarized by its own context and experience. Evidence that may seem compelling viewed through one lens may be virtually invisible, unconvincing or rejected through another. For example, research and independent inquiries might produce evidence that pricing instruments (e.g. carbon pricing) are economically efficient means of achieving a desired policy outcome (e.g. reductions in net greenhouse gas emissions), but such evidence may be ignored, contested or rejected through an ideological political lens if election commitments have explicitly and vociferously ruled out pricing carbon.

However if researchers, funders and end users are working closely together in a joint enterprise with shared goals and a high level of social capital, and if programme design pays close attention to the

accountabilities in Fig. 1, then over time the overall programme is more likely to be seen as useful and hence influential through all three lenses. Ministers and their officers seek feedback from clients and end users in making political judgements, and active engagement of civil servants with research programmes is likely to accelerate osmosis from research findings into organisational knowledge. A well-designed and managed transdisciplinary research programme is more likely to position itself in the 'sweet spot' in the centre of Head's Venn diagram than more conventional approaches wherein scientists carry out research in isolation, then publish their findings in academic journals, then lament the lack of uptake in policy. An anonymous reviewer of this paper put it well: "*engagement, dialogue, planning etc. all help to shift the polarities so that everyone can see the sweet spot.*"

The Australian science ministry examined the use of science in policy development in the Australian public service (DIISRTE, 2012) and concluded that the five key challenges to the use of science in policy development in the Australian public service are 'timeliness, cultural differences, relationships, timeframes and access to data and information'. A senior environmental policy maker at the workshop noted that the CERF–NERP programmes "*have been significant in building strong relationships between environment portfolio staff and researchers. But maintaining enduring relationships, particularly in the face of churn and changing priorities, remains a challenge.*"

As noted at the bottom of Box 1, and consistent with DIISRTE (2012), reward systems for researchers and policy makers differ markedly. The timeframes within which policy decisions need to be made are usually much shorter than a typical research project. Consistent with the doctrine of New Public Management (Hood, 1991), the Australian public sector is characterised by 'churn' or frequent turnover of personnel, a suspicion of deep subject matter expertise, preference for generic process skills and a default tendency to assume that any services can simply be purchased through competitive tendering processes. Consequently it is difficult and rare for staff inside government agencies to build sufficient domain expertise and/or researcher contacts to be able to understand, articulate or interrogate research needs, or to wish to be involved in iterative development of research programmes through negotiation with researchers and end users.

In our experience, these factors are prevalent across the modern public sector in Australia at all levels of government. They work against effective transdisciplinary research to inform policy.

Paradoxically, they also make investment in such research more essential.

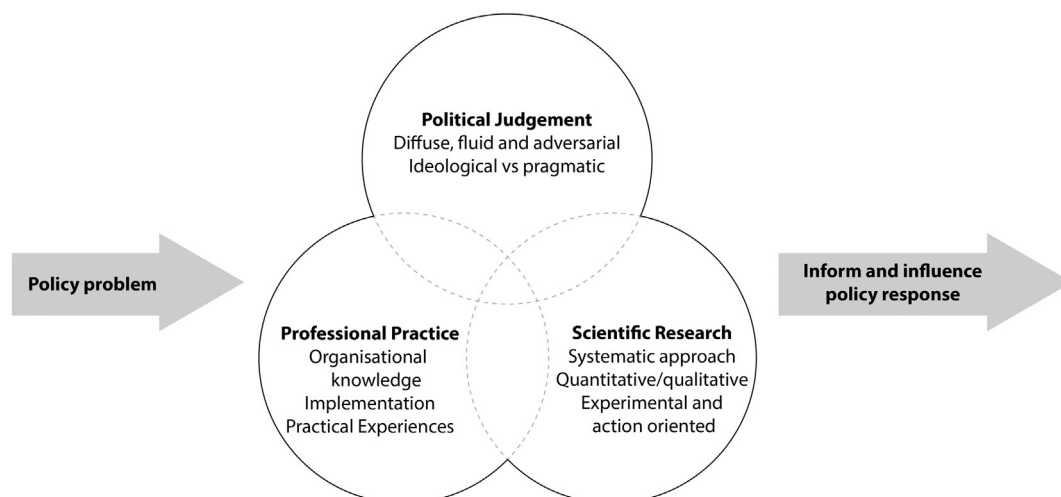


Fig. 3. Three lenses of knowledge and evidence through which public policy is informed. After Head (2008).

We found the framework developed by Roux et al. (2010) to be a useful starting point for framing a structured reflection among experienced research leaders to elicit lessons learned from the collective experience of five national research hubs over eight years.

There is a high level of consensus among the leaders of multi-institutional, transdisciplinary environmental research programmes in Australia that the chances of such research influencing and improving policy are maximised when research investments are designed such that funders, end users and researchers have *shared goals*, sufficient *continuity* of personnel to build *trust* and sustain *dialogue* throughout the research process from issue scoping to application of findings, and sufficient *flexibility* to be able to adjust and respond to new knowledge, changing circumstances and priorities. These design criteria are important for all three functional domains of researchers, end users and funders. Other accountabilities proposed by Roux et al. (2010) were also important for one or two functional domains as outlined in Fig. 1.

As this paper was being finalised, the Australian government was evaluating proposals for research hubs against six national environmental research priorities, for a new six-year \$125 m National Environmental Science Programme (NESP) from 2015. In a two-stage process, the detail of hub research plans is to be worked out through negotiation between the Department of the Environment and successful proponents in consultation with end users, with the Department acting as both a funder and end user. Hopefully that process will be characterised by shared goals, dialogue, trust, continuity and flexibility across researchers, funders and end users, extending from the planning phase over the six years of the Programme. It is encouraging that many of the lessons from CERF and NERP distilled in this paper appear to have informed the design of the NESP.

The diverse operating models of research hubs in the CERF and NERP prove that there is no single magic formula for the design and governance of multi-institutional, transdisciplinary environmental research programmes. In spite of this, there are important design criteria that all players – researchers, funders and end users – need to keep in clear focus as research investments are planned and implemented in order to realise an environmental benefit that exceeds the cost of the research.

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References

- Australian Standard Research Classification, 1998. Australian Bureau of Statistics, Canberra. Online resource available at: <http://www.abs.gov.au/Ausstats/abs@nsf/66f306f503e529a5ca25697e0017661f/2d3b6b2b68a6834fca25697e0018fb2d1/OpenDocument>.
- Bammer, G., 2013. *Disciplining Interdisciplinarity; Integration and Implementation Sciences for Researching Complex Real-World Problems*. ANU ePress.
- Bielak, A., Campbell, C.A., Pope, S., Schaefer, K., Shaxson, L., 2008. From Science Communication to Knowledge Brokering: The Shift from 'Science Push' to 'Policy Pull'. In: Cheng, D., Claessens, M., Gascoigne, T., Metcalfe, J., Schiele, B., Shi, S. (Eds.), *Communicating Science in Social Contexts: New Models, New Practices*. Springer, Dordrecht, pp. 201–226.
- Brown, V.A., Harris, J.A., Russell, J.Y. (Eds.), 2010. *Tackling Wicked Problems: Through the Transdisciplinary Imagination*. Earthscan, London.
- Burns, M., Weaver, A. (Eds.), 2008. *Exploring Sustainability Science: A Southern African Perspective*. Sun Press, Stellenbosch.
- Campbell, C.A., Schofield, N., 2007. *The Getting of Knowledge – A Guide to Funding and Managing Applied Research*. Land & Water Australia, Canberra (Online resource available at: <http://lwa.gov.au/files/products/land-and-water-australia-corporate/pr061240/pr061240.pdf>).
- Canadian Health Services Research Foundation, 2003. *The Theory and Practice of Knowledge Brokering in Canada's Health System*. CHSRF, Ottawa.
- Clark, W.C., Dickson, N.M., 2003. Sustainability science: the emerging research program. *Proc. Natl. Acad. Sci.* 100, 8059–8061.
- DEWHA, 2010. Program Guidelines for the National Environmental Research Program. Australian Government Department of the Environment, Water, Heritage and the Arts, Canberra (Online resource available at: <http://www.environment.gov.au/system/files/pages/383521ff-cb5f-4384-b1b0-084142a4d320/files/national-environmental-research-program-guidelines.pdf>).
- DIISRTE, 2012. APS200 Project: The Place of Science in Policy Development in the Public Service. Australian Government Department of Industry, Innovation, Science, Research and Tertiary Education, Canberra (Online resource available at: <http://www.industry.gov.au/science/Pages/APS200ProjectScienceinPolicy.aspx>).
- DoF, 2014. Commonwealth Procurement Rules; Achieving Value for Money. Australian Government Department of Finance, Canberra (Online resource available at: <http://www.finance.gov.au/procurement/procurement-policy-and-guidance/commonwealth-procurement-rules/>).
- Economic, environmental and social impacts of the Cooperative Research Centres program, 2012. Report by the Allen Consulting Group to the Department of Industry, Innovation, Science, Research and Tertiary Education, Canberra. Online resource available at: <http://crca.asn.au/economic-social-and-environmental-impacts-of-the-cooperative-research-centres-program/>.
- Francis, R.A., Goodman, M.K., 2010. Post-normal science and the art of nature conservation. *J. Nat. Conserv.* 18, 89–105.
- Fry, G., 2001. Multi-functional landscapes – towards transdisciplinary research. *Landsc. Urban Plan.* 57, 159–168.
- Funtowicz, S.O., Ravetz, J.R., 1993. Science for the post-normal age. *Futures* 25 (7), 735–755.
- Gibbons, P., Zammit, C., Youngentob, K., et al., 2008. Some practical suggestions for improving engagement between researchers and policy-makers in natural resource management. *Ecol. Manag. Restor.* 9 (3), 182–186.
- Head, B.W., 2008. Three lenses of evidence-based policy. *Aust. J. Public Adm.* 67 (1), 1–11.
- Holley, C., 2010. Public participation, environmental law and new governance: lessons for designing inclusive and representative participatory processes. *Environ. Plan. Law J.* 27, 360–391.
- Hood, C., 1991. A public management for all seasons. *Public Adm.* 69, 3–19.
- Klein, J., 2008. Evaluation of interdisciplinary and transdisciplinary research. *Am. J. Prev. Med.* 35 (2S), S116–S123.
- Michaels, S., 2009. Matching knowledge brokering strategies to environmental policy problems and settings. *Environ. Sci. Policy* 12, 994–1011.
- NCCARF, 2014. NCCARF 2008–2013: The First Five Years. National Climate Change Adaptation Research Facility (Online resource available at: <http://www.nccarf.edu.au/content/nccarf-2008-2013-first-five-years>).
- Newell, W.H., 2001. A theory of interdisciplinary studies. *Issues Integr. Stud.* 19, 1–25.
- Productivity Commission, 2011. Inquiry Report No 52. Rural Research and Development Corporations, Canberra (Online resource available at: <http://econpapers.repec.org/bookchap/risprod/0052.htm>).
- Repko, A.F., 2008. *Interdisciplinary Research – Process and Theory*. Sage, London.
- Roux, D.J., Stirzaker, R.J., Breen, C.M., Lefroy, E.C., Cresswell, H.P., 2010. Framework for participatory reflection on the accomplishment of transdisciplinary research programs. *Environ. Sci. Pol.* 13, 733–741.
- Spencer, C., McVay, P., Sheridan, S., 2014. Evaluation of the National Environmental Research Program (NERP). (Online resource available at: http://www.environment.gov.au/system/files/pages/b9d8cb4e-6ff6b-414b-aaa2-08d6d528b388/files/nerp-evaluation-final-report_0.pdf).
- Tress, B., Tress, G., Fry, G., 2005a. Integrative studies on rural landscapes: policy expectations and research practice. *Landsc. Urban Plan.* 70, 177–191.
- Tress, B., Tress, G., Fry, G., 2005b. Researchers experiences, positive and negative, in integrative landscape projects. *Environ. Manag.* 36 (6), 792–807.
- Urbis, 2010. Evaluation of the Commonwealth Environment Research Facilities Program. Online resource available at: <http://www.environment.gov.au/system/files/resources/f52f870c-f3d5-4cd8-9a48-f465699b26a5/files/cerf-evaluation-report.pdf>.

Appendix A. Research hubs of the National Environmental Research Program (NERP) and their antecedent hubs of the Commonwealth Environmental Research Facilities (CERF) programme

Hub	Research focus	Scientific disciplines	# research providers*	# researchers		Funding		
				CERF 2007–2011	NERP 2011–14	CERF 2007–2011	NERP 2011–14	Total 2007–14
NERP environmental decisions hub (CERF applied environmental decision analysis)	Understanding major biodiversity drivers to maintain ecosystems and maximise their resilience against human impacts	<ul style="list-style-type: none"> • Climate science • Ecology • Economics • Public policy 	9 Core partners: <ul style="list-style-type: none"> • ANU • CSIRO • NSW OEH • PV • RMIT • UMelb • UQ • UWA • VDEPI 	108	118	CERF: \$7.81 M Co-contributions: \$9.9 m Total: \$27.71 m	NERP: \$11 m Co-contributions: \$6.4 m Total: \$17.4 M	Australian government: \$18.81 m Co-contributions: \$16.3 m Total: \$35.11 m
NERP landscape and policy hub (CERF landscape logic)	Retrospective evaluation of the impact of public environmental funding. Regional scale assessment of biodiversity including social and institutional drivers and functional attributes.	<ul style="list-style-type: none"> • Geography • Climate science • Ecology • Economics • Hydrology • Public policy • Social science 	7 <ul style="list-style-type: none"> • ACE • ANU • CSIRO • CSU • GU • MU • UTAS 	58	37	CERF: \$8.75 Co-contributions: \$12.32 m Total: \$21.07 m	NERP: \$6 M Co-contributions: \$9.2 m Total: \$15.2 m	Australian government: \$14.75 m Co-contributions: \$21.52 m Total: \$36.27 m
NERP marine biodiversity hub (CERF marine biodiversity hub)	Provision of biodiversity and baseline data to underpin marine decision making, particularly in reference to marine bioregional planning, protected areas and natural resource management	<ul style="list-style-type: none"> • Earth science • Fisheries • Marine biology • Oceanography • Public policy • Remote sensing 	7 <ul style="list-style-type: none"> • AIMS • CDU • CSIRO • GA • MVic • UTAS • UWA 	45	102	CERF: \$6.6 M Co-contributions: \$12.64 Total: \$19.24	NERP: \$11 m Co-contributions: \$18.6 m Total: \$29.6 M	Australian government: \$17.6 m Co-contributions: \$31.24 m Total: \$48.84 m

(continued on next page)

Appendix A (continued)

Hub	Research focus	Scientific disciplines	# research providers*	# researchers		Funding		
				CERF 2007–2011	NERP 2011–14	CERF 2007–2011	NERP 2011–14	Total 2007–14
NERP Northern Australia hub (CERF tropical rivers and coastal knowledge)	Improvement of biodiversity outcomes in northern Australian terrestrial, freshwater and estuarine systems. Combining biodiversity monitoring and reporting with adaptive planning and community based natural resource management to improve biodiversity outcomes and Indigenous livelihoods	<ul style="list-style-type: none"> • Agricultural science • Ecology • Limnology • Marine biology • Natural resource management • Planning • Public policy • Traditional knowledge 	16	113	59	CERF: \$8.8 M Co-contributions: \$11 m Total: \$19.8 m	NERP: \$14.7 m Co-contributions: \$15.8 m Total: \$30.5 M	Australian government: \$23.5 m Co-contributions: \$26.8 m Total: \$50.3 m
NERP tropical ecosystems hub (CERF marine and tropical sciences research facility)	Improvement of scientific understanding and environmental decision making in far north Queensland with particular reference to the Great Barrier Reef, rainforests of the Wet Tropics and Torres Strait	<ul style="list-style-type: none"> • Climate change • Ecology • Fisheries • Limnology • Marine biology • Natural resource management • Public policy • Traditional knowledge 	13	267	242	CERF: \$37.2 m Co-contributions: \$45 m Total: \$82.2 m	NERP: \$28.5 M Co-contributions: \$33.4 m Total: \$61.9 m	Australian government: \$65.7 m Co-contributions: \$78.4 m Total: \$144.1 m
Australian government Partners						\$69.16 m	\$71.2 m	\$140.36 m
Total			52	591	558	\$160.02 m	\$154.6 m	\$314.62 m

*ACE: Antarctic Climate and Ecosystems Cooperative Research Centre, AIMS: Australian Institute of Marine Science, ANU: Australian National University, AR: Apudthama Rangers, AWC: Australian Wildlife Conservancy, BCYDC: Balkanu Cape York Development Corporation, CDU: Charles Darwin University, CSIRO: Commonwealth Scientific and Industrial Research Organisation, CSU: Charles Sturt University, Djelk: Djelk Rangers (Bawinanga Aboriginal Corporation), JCU: James Cook University, GA: Geoscience Australia, GAC: Giringun Aboriginal Corporation, GBRMPA: Great Barrier Reef Marine Park Authority, GU: Griffith University, LLR: Lama Lama Rangers, MU: Macquarie University, MVic: Museum of Victoria, NAILSMA: Northern Australian Indigenous Land and Sea Management Alliance, NSWOE: New South Wales Office of Environment and Heritage, NTLRM: Northern Territory Department of Land Resource Management, PV: Parks Victoria, RAPA: Rainforest Peoples Aboriginal Alliance, RMIT: Royal Melbourne Institute of Technology, TSRA: Torres Strait Regional Authority, UMelb: University of Melbourne, UQ: University of Queensland, USyd: University of Sydney, UTAS: University of Tasmania, UTS: University of Technology Sydney, UWA: University of Western Australia, VDEPI: Victorian Department of Environment and Primary Industries, WLML: Warrdeken Land Management Limited, WGAG: Wunambal-Gaambera Aboriginal Corporation, WTMA: Wet Tropics Management Authority.