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Collaboration mobilises institutions with scale-dependent comparative advantage in landscape-scale biodiversity conservation

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ABSTRACT

Landscape-scale approaches are emerging as central to ecosystem management and biodiversity conservation globally, triggering the requirement for collaboration between multiple actors and associated risks including knowledge asymmetries; institutional fragmentation; uncertainty; power imbalances; "invisible" slow-changing variables; and entrenched socio-economic inequities. While social science has elucidated some dimensions required for effective collaboration, little is known about how collaboration manages these risks, or of its effects on associated social-ecological linkages. Our analysis of four different Australian contexts of collaboration shows they mobilised institutions matched to addressing environmental threats, at diverse scales across regulatory and non-regulatory domains. The institutions mobilised included national regulatory controls on development that threatened habitat, incentives to farmers for practice-change, and mechanisms that increased resources for on-ground fire and pest management. Knowledge-sharing underpinned effective risk management and was facilitated through the use of boundary objects, enhanced multi-stakeholder peer review processes, interactive spatial platforms, and Aboriginal-driven planning. Institutions mobilised in these collaborations show scale-dependent comparative advantage for addressing environmental threats. The findings confirm the need to shift scientific attention away from theorising about the ideal-scale for governance. We argue instead for a focus on understanding how knowledge-sharing activities across multiple scales can more effectively connect environmental threats with the most capable institution to address these threats.

1. Introduction

Ecosystems and biodiversity need to be managed and conserved at the landscape scale to ensure the provision of many services including freshwater, climate regulation and habitats for species of both commercial and conservation value (Prager et al., 2012). Landscape-scale biodiversity conservation approaches are gaining recognition as key tools alongside, or alternative to, species-focused and protected

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area methods (Wyborn and Bixler, 2013). The move to broader scales requires collaboration between multiple social actors and integration of knowledge about diverse social components (values, culture, communities, households, technologies, markets) together with multiple ecosystem components (wind, water quality, fires, habitat distribution, species populations) that vary spatially and temporally (Ommer et al., 2012).

The drivers and effects of multiscalar collaboration in landscape-scale biodiversity conservation and management are receiving increasing scientific attention, including through systematic typologies to help interrogate the diversity of contexts (Hill et al., 2012; Robinson et al., 2011). Effective social conditions for collaboration have been shown to be supported by authentic dialogue between diverse stakeholders who have interdependent interests in particular issues or planning contexts (Innes and Booher, 2010). Severe, complex environmental problems often create the social conditions for collaborations to form because the benefits of working together outweigh the transaction costs, provided there is appropriate leadership, social and human capital and access to funding (Benson et al., 2013). Relational dynamics within collaborators' social networks are key to effective learning (Lejano and Ingram, 2009). However, the linkages between the social conditions of collaboration and environmental outcomes have been little investigated and remain unclear (Plummer et al., 2012; Wyborn and Bixler, 2013). In Australia, where environmental management has substantially relied on collaborative approaches over the last two decades, a recent review identified a continued decline in environmental conditions and highlighted the need for better understanding of the impacts of collaboration on environmental institutions and conditions (Jacobson et al., 2014). In this paper, we present an Australian multi-case study analysis, based on a social-ecological systems approach, of how collaboration manages risks that are triggered by landscape-scale approaches to biodiversity conservation. Our analysis highlights the capacity of collaboration to mobilise institutions that have *scale-dependent comparative advantage* for biodiversity conservation. We also found some evidence that mobilising these institutions slowed the rates of biodiversity declines, which nevertheless continues.

Proponents identify the strengths of collaboration as: producing more informed, creative, and adaptive solutions; building individual and social capacity; achieving consensus, thereby avoiding costly disputes; supporting processes for shaping and implementing regulatory policy; and improving social and environmental outcomes (Susskind et al., 2012). Critics argue that collaboration: delegitimizes legal institutions for resolving conflict; co-opts environmental advocates; dis-empowers national and international conservation interests; impedes recognition of the rights of Aboriginal peoples; entrenches socio-economic marginalisation, and produces lowest common denominator solutions (McKinney and Field, 2008; von der Porten and de Loe, 2013). Innes and Booher (2010) concluded from their multi-decadal study that the overall impact of effective collaboration is to produce long-term social and institutional learning that promotes systemic adaptation. Linkages with social-ecological systems (SES) science offer pathways to extend this understanding by also focusing attention on environmental considerations (Wilkinson, 2012).

SES science emphasises the dynamic and interactive aspects of people-environment relationships and features such as non-linearity, cross-scale interactions, linkages amongst fast and relatively slow changing variables, thresholds and surprise (Folke, 2006). It focuses primarily on promoting sustainability. Attention to collaboration has arisen from recognition that participation builds trust, and deliberation leads to the shared understanding needed for self-organization and for connections across polycentric decision making nodes, enabling ongoing adaptive governance for sustainability (Lebel et al., 2006). SES analysis has proposed that collaboration enables solutions to sustainability issues such as climate change through a *risk management* approach (May and Plummer, 2011). Particular risks triggered in landscape-scale biodiversity conservation include: knowledge asymmetries; institutional diversity and fragmentation; uncertainty; power imbalances; "invisible" slow-changing variables (e.g. incremental habitat loss, erosion of intergenerational knowledge transfer); and entrenched socio-economic disadvantage and marginalisation (Pert et al., 2010). Mauelshagen et al. (2014) demonstrate that effective risk management in environmental policy-making requires systematic knowledge management to enable traditional vertical knowledge dissemination to be supported by more effective lateral knowledge-sharing. SES analyses have also proposed that the management of power imbalances through collaboration can mobilise connections between knowledge and social learning that produce *generative power*, a potent channel for structuring social-ecological system change towards sustainability (Hendriks, 2009; Hill et al., 2013).

These propositions regarding the effect of collaboration on risk management and power relations, and the recognised potential of SES science to elucidate social-ecological linkages, underpin our approach to understanding how collaboration supports institutions for biodiversity conservation. We used a common enquiry framework to analyse four Australian case studies of collaborative environmental management. The framework enabled investigation of six dimensions of risk and outcomes for biodiversity conservation institutions from landscape-scale collaborations. In this paper, we firstly present our methods for data collection, analysis and synthesis, followed by a description of the biodiversity and institutional context, and start-up processes for each of the case studies. We then present the results of our analysis, and discuss the significance and implications of our research findings.

2. Methods

Our research used the techniques of multiple cross-case study synthesis (Yin, 2009), applied to investigate four cases that were originally conducted as independent research studies. These prior studies had engaged one or more co-authors as research leaders or team members in multi-stakeholder collaborations for landscape-scale biodiversity conservation. Eleven prospective studies were initially identified from diverse social-ecological contexts, mainly in northern Australia (Table 1, Fig. 1).

Comparative analysis involved four stages (Fig. 2). First, eight researchers who had been involved in each of the 11

Table 1 – Focus and selection outcome of case studies from prospective prior studies.

Title and key source	Focus	Selected for analysis using common enquiry framework, or not, with comment
Anpernirrentye framework for Indigenous ecological knowledge collaboration (Walsh et al., 2013)	Part of a larger Traditional Ecological Knowledge collaboration with Natural Resource Management Board in central Australia	Not selected; one part of a nested design; resources unavailable to investigate the larger collaboration in which it nests
Eastern Kuku-Yalanji IPA (Pert et al., 2015)	Collaborative development of a management plan to support declaration of a multi-tenured IPA	Not selected; insufficient data available about the process of collaboration
Future Scenarios for the *Great Barrier Reef* (GBR) (Bohnet, 2010)	Contribution to early planning phase regarding a range of development issues (port expansion, dredging)	Not selected; prior study focus was too narrow to provide data about the process of collaboration and outcomes
Water Quality: GBR Water Quality Improvement Planning (WQIP) (Kroon et al., 2009; Lane and Robinson, 2009)	Development and implementation of Reef Water Quality Improvement Plan at GBR-wide and Tully Catchment levels	*Selected*; includes a nested design with Tully WQIP as first major plan at single catchment scale, and GBR-wide Reef Partnerships collaboration
Martu Collaborative Atlas for Country (Carty et al., 2013)	Collaborative mapping of biodiversity and cultural values in the Western Desert	Not selected; prior study focus was too narrow to provide data about the process of collaboration and outcomes
Protected Area Co-management: Miriuwung-Gajerrong Joint Park Planning (Hill, 2011)	Collaboration for developing and implementing the first management plan for the first Aboriginal joint-managed parks in WA	*Selected*; collaboration including implementation of the management plan
Habitat Planning: Mission Beach Habitat Network Action Plan (Hill et al., 2010)	Development and implementation of a plan for the protection of habitat in one part of the Australian humid tropical forests	*Selected*; information rich with multiple data-sources; convergent triangulation in case description
New Zealand-Australia Joint Park Management Collaboration, Te Urewera in a landscape context (Lyver et al., 2014)	Collaboration on models for recognition of indigenous management principles in protected areas	Not selected; prior study focus was too narrow to provide data about the process of collaboration and outcomes
Our Country Our Way: Guidelines for *Australian IPAs* (Indigenous Protected Areas) Management Plans (Davies et al., 2013)	Collaboration with more than 100 IPA managers to produce a set of guidelines for Indigenous-led and collaborative managed IPAs	Not selected; prior study focus was too narrow to provide data about the process of collaboration and outcomes
Paruku Desert Lake art-science collaboration (Morton et al., 2013)	Collaboration between Walmajarri people, artists and scientists to highlight values of the protected area	Not selected; prior study focus was too narrow to provide data about the process of collaboration and outcomes
Water Resources: Wet Tropics Water Resources Plan (Maclean, 2015)	Bringing indigenous values, knowledge and interests into the water resources plan	*Selected*; collaboration including its implementation into the Water Resources plan for the wet tropics catchment

prior studies independently reviewed data (e.g. reports, meeting minutes, web-pages, participant-observation notes, working documents, agendas, media releases, interviews and focus group transcripts) and publications. Stage 2 involved three steps: a workshop, in September 2011, in which the eight researchers presented insights about collaboration for biodiversity from each prior study. Two propositions emerged from discussion of common features: that collaboration enables solutions to biodiversity conservation problems through (1) managing diverse risks encountered at the landscape scale; and (2) mobilising generative power. A literature review was next undertaken, which confirmed these propositions as important to theoretical debates. Finally, the eight researchers developed a Common Enquiry Framework (CEF) to enable cross-case study analysis of the two propositions and relevant conditions (Table S1). The information-orientated approach (Flyvbjerg, 2006) applied in the preliminary analysis indicated that four of the eleven studies had sufficiently rich data sources available to enable the propositions to be examined through researcher responses to the CEF. The other seven cases contributed only to the generation of the propositions and the CEF. Each of the four cases analysed is distinct and different as is each context and process of collaboration. The four cases are considered replicates to investigate theory (not replicates in the sense of experimental design) having been selected according to the theoretical standpoint established through the earlier steps of Stage 2 (Yin, 2009).

Supplementary Table S1 related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.envsci.2015.04.014.

In Stage 3, co-authors answered the questions in the CES (Table S1), drawing on their previously assembled data and publications. The CES and answers were imported into N-Vivo software for cross-case analysis in Stage 4. Thematic and cluster analysis of CES answers resulted in six additional constructs: authentic dialogue; blockage; co-author role; interdependence; knowledge-sharing and power-sharing. All coding was undertaken first by one researcher, and then independently by a second researcher. Analytical replication logic was used to identify common findings and to draw implications for the initial propositions and theory, which we present as results (Section 4). Descriptions of collaboration

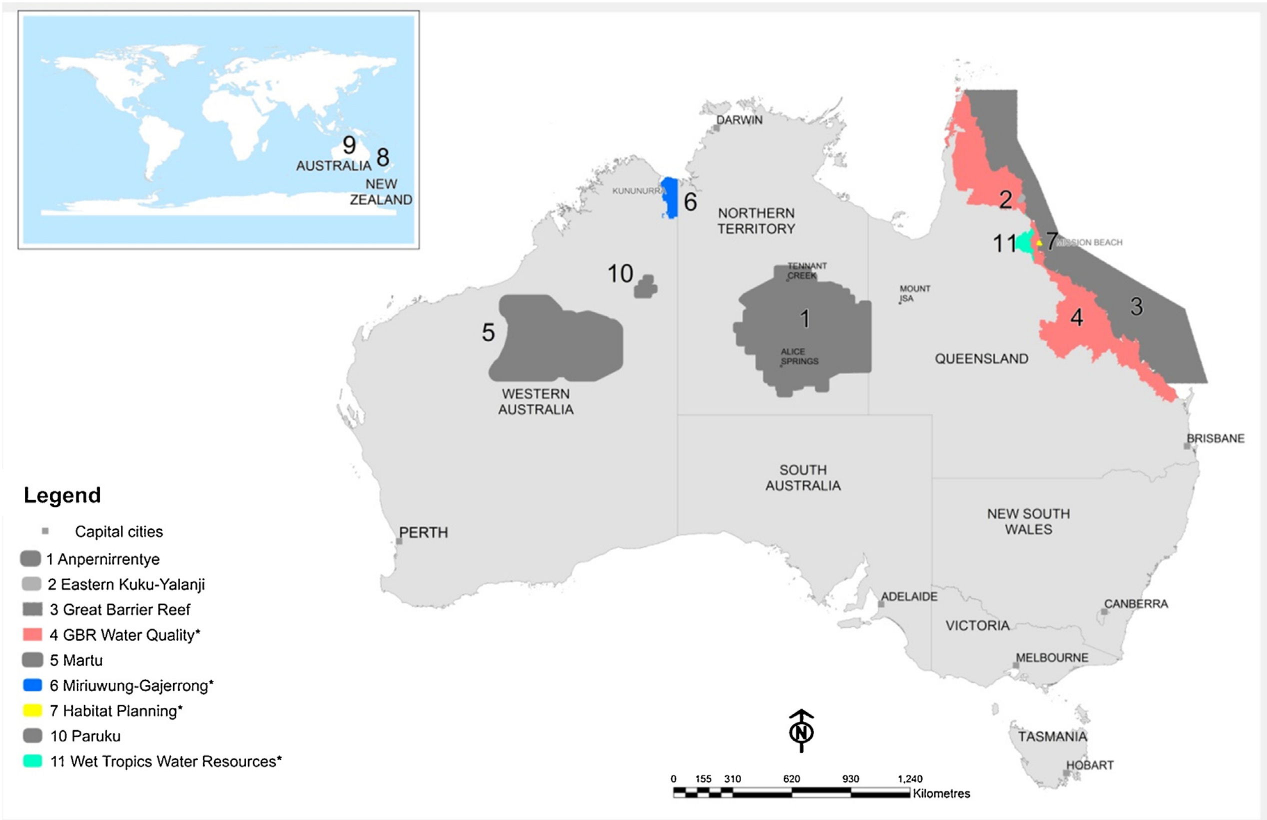

Fig. 1 – Locations of studies, including those initially identified as prospective for investigation of collaborations, with the four case studies selected for cross-case analysis marked by*.

triggers and initiation for each case study are first presented (Section 3) which draw from the first five elements of the CEF, while Section 4 draws on the next fifteen CEF elements (Table S1). Section 4.1 addresses evidence for collaboration in the case studies managing risks at landscape scale. Section 4.2 describes how these efforts mobilised generative power and institutions for biodiversity conservation, and the outcomes from these actions.

3. Description of the case studies: key biodiversity values and threats, context, and getting started

Each case study focused on different biodiversity components, both terrestrial and aquatic, from local to regional scales:

Habitat Planning: Habitat Network Action Plan, Mission Beach;
Water Quality: Water Quality Improvement Planning, Great Barrier Reef (GBR) Catchments;
Protected Area Co-Management: Miriuwung-Gajerrong (MG) Joint Park Planning; and
Water Resources: Wet Tropics Water Resources Plan.

Biodiversity values, major threats, institutional context, and how the collaboration started are described below for each case, with key information summarised in Table 2.

3.1. *Habitat Planning: Habitat Network Action Plan, Mission Beach*

Biodiversity values, threats and the institutional context: The Mission Beach narrow coastal plain, in which rainforest, reef, sandy beaches, and near-shore islands are juxtaposed, is a key site for tropical humid rainforest biodiversity including the endangered southern cassowary (Hill et al., 2010). Threats to biodiversity include habitat loss, fragmentation and degradation, roads and traffic movement, dog attacks and cyclones. By 2006 multiple actors were addressing these issues including through conservation and natural resource management (NRM) planning by Australian, Queensland (State), regional and local government agencies, and through research, community and Aboriginal Traditional Owner initiatives (Pert et al., 2010).

Getting started: Ongoing declines in habitat and cassowary conservation values were the trigger for collaboration. The regional NRM agency, Terrain NRM, invited interested stakeholders to a roundtable that established the Mission Beach Habitat Network Action Plan Committee. Sixteen invitees were identified from government, community and industry organisations or interests through institutional analysis, interview and chain sampling, and one group self-nominated (Hill et al., 2010). The Action Committee set the goal of developing an ecologically viable habitat network that protects community values. They produced the Mission Beach Habitat Network Action Plan to implement their vision (Hill et al., 2010).

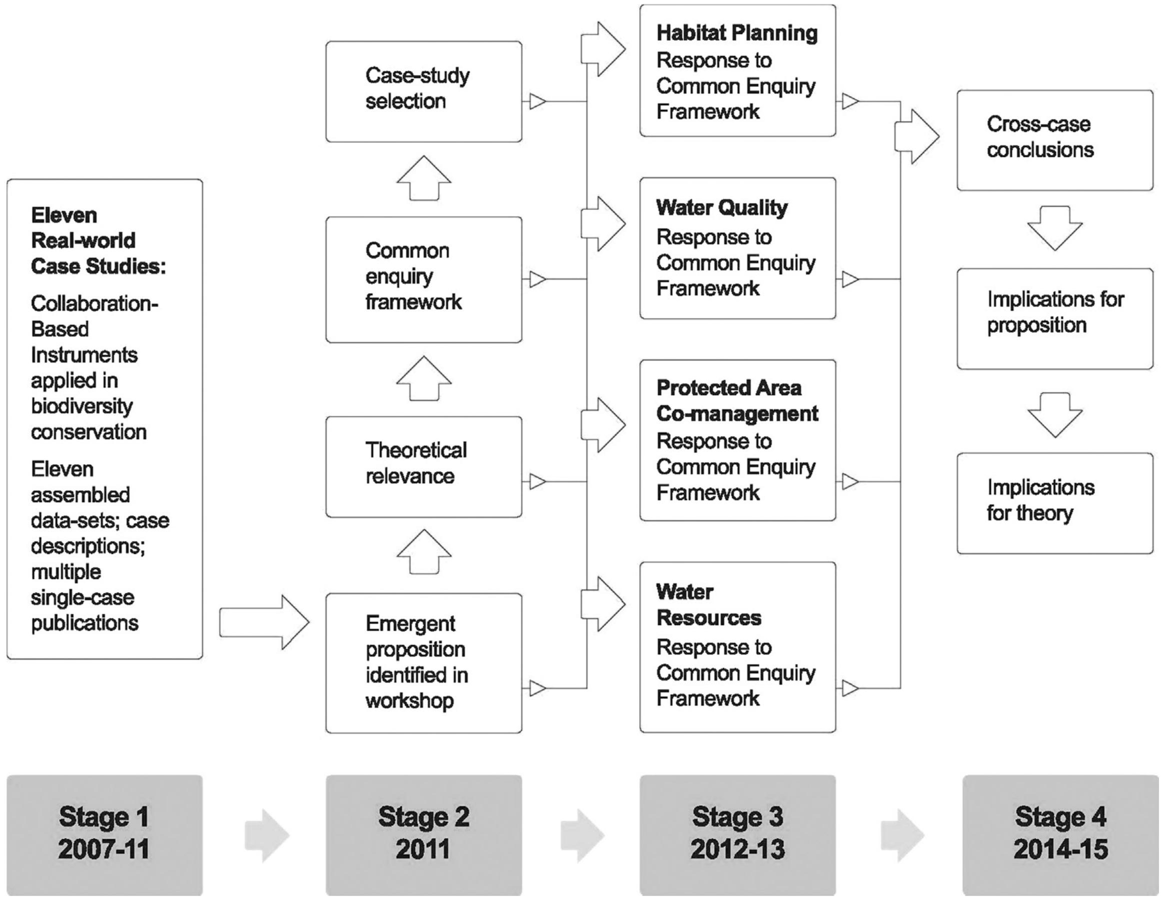

Fig. 2 – Stages in multi-case study analysis
***Source:* Modified from Yin (2009).**

3.2. *Water Quality: Water Quality Protection Plan, Great Barrier Reef Catchments*

Biodiversity values, threats and the institutional context: The Great Barrier Reef (GBR) World Heritage Area is a global icon for its biodiversity significance and natural beauty. However, nutrients and sediments from its 35 river catchments impact significantly on its health causing changes in coral and fish species composition, population outbreaks of Crown-of-Thorns starfish, and increased macro-algal cover (Butler et al., 2013). The Reef Water Quality Improvement Plan, released jointly by the Australian and Queensland (State) governments in 2003, required development of catchment-based plans to identify and support voluntary implementation of measures to halt diffuse pollution. It assigned responsibility for water quality improvement to regional natural resource management (NRM) agencies (Robinson et al., 2011, 2014).

Getting started: The Reef Water Quality Partnership brought five NRM agencies together with relevant government departments in the GBR catchments. They collaborated to establish common goals and achieved significant funding support (Robinson et al., 2011). The Tully-Murray was one of the GBR catchments where integrated research/management efforts triggered fine-scale collaboration (Kroon et al., 2009). Terrain NRM brought together a Steering Committee and Action Teams of 14 different interest-groups, selected through group discussion, expert opinion and snowball methods, who produced the Draft Tully-Murray Water Quality Improvement Plan.

3.3. *Protected Area Co-Management: Miriuwung Gajerrong Joint Park Planning, Ord River basin*

Biodiversity values, threats and the institutional context: The Ord River basin in north-west Australia is recognised internationally for its Ramsar-listed wetlands, including populations of endangered fish and large aggregates of waterbirds, and for relatively intact tropical savannas and associated rare fauna. Threats to biodiversity include alteration to water flows and fire regimes, and pervasive impacts of feral animals and invasive weeds (Government of Western Australia, 2011). The Ord Final Agreement, concluded in 2005 between Miriuwung-Gajerrong (MG) native title holders, the Western Australian State Government (WA) and private sector interests, paved the way for expansion of irrigated agriculture in the Ord Catchment. Negotiation of the agreement had established an adversarial relationship between the WA government and MG since MG people ultimately had no choice about agreeing: compulsory acquisition of their native title would have been highly likely had negotiations broken down. The opportunity

Table 2 – Overview of the context, key biodiversity values, key threats and how the collaboration started for each case study.

Collaboration context	Key biodiversity values and places	Key threats to biodiversity	Getting started
Habitat Planning	Lowland tropical humid rainforest patches within and adjacent to the Wet Tropics World Heritage Area; cassowary populations	Habitat loss through real-estate subdivision and agricultural intensification; traffic strikes, dog attacks, cyclones	Action Committee started by regional natural resource management agency and research organisation
Water Quality	Water quality in the catchments draining into the Great Barrier Reef World Heritage Area	Diffuse pollution from agriculture is main source of excess nutrients driving poor water quality	Reef Water Quality Improvement Plan triggered regional NRM agencies to put together partnerships at regional and local scale
Protected Area Co-management	Relatively intact savanna landscapes and wetlands of the Ord River in the East Kimberley Parks. Rare and threatened fauna	Changes to fire regimes and water flow regimes, weed and pest species	Native title agreement: joint management established for six parks as compensation for acquisition of other land. Actors moved from negotiation to collaboration
Water Resources	Freshwater resources and rivers of the wet tropics region, including those in the World Heritage Area e.g. 30 wetlands of national importance and 42% of Australia's fish species	Key water-dependent biota and habitat are threatened by water extraction and resultant changes in flow regimes	National Water Initiative & Guidelines. Actors enabled contribution of Aboriginal knowledge about one water-dependent species

for MG people to jointly manage six proposed conservation parks, in partnership with the WA Department of Environment and Conservation (DEC) and the Conservation Commission of WA (CCWA), was part of the package of measures negotiated as compensation for flooding and agricultural development of other parts of their traditional lands (Hill, 2011).

Getting started: Collaboration was triggered by the requirement for MG and the WA Department of Environment staff to begin jointly managing the parks. MG people first developed a cultural planning framework for the parks, then spent time working with the WA agencies to develop joint planning guidelines. They subsequently collaborated with a wider group of stakeholders to develop park management plans.

3.4. *Water Resources: Aboriginal water values in the Australian wet tropics*

Biodiversity values, threats and the institutional context: The freshwater resources in the wet tropics bioregion support key ecological assets, including 30 wetlands of national importance, and 42% of Australia's fish species (DNRM and DSITIA, 2014). 154 of the 6400 identified environmental assets are considered to be critically linked to freshwater flow regimes. Key biota and critical habitats face risks from water extraction for a range of farming, industrial and domestic purposes (DNRM and DSITIA, 2014). Competition for available resources peaks in the dry season. The National Water Initiative (NWI), agreed between Australian and State governments in 2004, established a framework for water planning including requirements for engagement with the community and with Aboriginal peoples, their values and interests (Jackson et al., 2012). The *Water Resource (Wet Tropics) Plan 2013* was developed under the *Water Act (Queensland) 2000* to implement the NWI in this region.

Getting started: Initial engagement by Aboriginal peoples, triggered by the NWI requirements, was through government managed information strategies (Maclean et al., 2015). Girringun Aboriginal Corporation, representing nine Aboriginal Traditional Owner groups in the southern wet tropics bioregion, provided a written submission and advice to a Technical Committee, and participated in a community reference panel and an engagement process run by Terrain NRM. Chance interactions between aquatic ecologists and two co-authors led to a more collaborative process starting. Art was used, in an on-country workshop involving only Aboriginal people and the researchers, as a medium for Aboriginal people to express water values, knowledge and management aspirations to the researchers (Robinson et al., 2015). A subsequent collaborative workshop involved, in addition, one Girringun representative, and two aquatic ecologists (with two other agency staff as observers). Researchers later interviewed some participants from the art workshop about one of the species that ecological assessments had identified as a water-dependent asset: the fresh water eel.

4. Results

4.1. *Collaboration as risk management*

Our analysis examined all aspects of the case study collaborations in relation to the six identified dimensions of risk. These are considered in turn below: knowledge asymmetries; institutional diversity and fragmentation; uncertainty; ''invisible'' slow-changing variables; power imbalances; and socio-economic marginalisation and disadvantage.

4.1.1. *Knowledge asymmetries*

Four different types of knowledge asymmetries were identified across the case studies. We give one example from each. First is the asymmetry arising from differences between scientific knowledge-holders and holders of Aboriginal and/or local knowledge. The *Reef Water Quality* case study highlighted this starkly: scientists viewed the major issue as nitrogen and pesticides from agricultural practices being transported by run-off into rivers, whereas local groups saw water quality issues as arising from feral pigs, weeds and river bank erosion. Second is the asymmetry within Aboriginal societies. This arises in part from cultural protocols that associate knowledge acquisition rights with age, gender and land ownership under customary law. Non-Aboriginal partners did not always understand how to navigate these differences. However, even more problematic knowledge asymmetries within Aboriginal groups were caused by historical/colonial processes that had moved children away from their families, prevented inter-generational and ceremonial knowledge transfer, and prohibited use of indigenous languages. The *Protected Area* case study highlighted these asymmetries: conflicts occurred between knowledge holders who were not customary-law owners, and customary-law owners who did not hold knowledge.

The third knowledge asymmetry arose from differences between the knowledge held by different types of scientists, for example in the *Habitat Planning* case study in relation to methods for assessing cassowary populations. Fourth was the difference between the knowledge held by different groups of local people. For example, in the *Habitat Planning* case study, all local groups agreed that conserving cassowaries was important. However, there was much less agreement about the importance of cassowary habitat, and conflict over the drivers of habitat loss. Sometimes these different types of asymmetry occurred simultaneously: in the *Water Quality* case study, the regional NRM organisations expressed frustration that models rather than management expertise or ecological knowledge of streams continued to be the dominant basis of knowledge.

Diverse approaches were used to address the asymmetries. The stakeholder committees in the *Habitat Planning* and *Water Quality* case studies adopted an approach of transparent knowledge-sharing and open review. Both commissioned reports through collaborative processes. They agreed on terms of reference and selection of appropriate experts, received and reviewed presentations from authors at committee meetings, reviewed written drafts of the reports, and ensured these were finalised to include various perspectives. In the *Water Quality* case study, collaborative meetings were organised to blend the expertise offered by scientists, regional NRM planners and rural industry groups in design of water quality action programs and in measuring their efficacy (Robinson et al., 2014). Ultimately causes of water quality decline considered important by scientists and those considered important by locals were all recognised. In the *Water Resources* case study, participatory mapping was used to negotiate different knowledge claims within the Aboriginal groups and deliver a report that sat alongside the environmental science report as part of the knowledge basis for the plan (Robinson et al., 2015). The *Protected Area* case study deployed a trip to a specific area on country with a group of senior men, both knowledge holders and others, to overcome knowledge asymmetries within the Aboriginal societies.

A range of tools were used to link local, Aboriginal and scientific knowledge. Boundary objects deployed included artwork, maps, posters and photographs of species of common interest. In the *Habitat Planning* case study, the cassowary functioned as collaborative focal species that bridged between different groups of knowledge holders (Hill et al., 2010). Threat-based scenarios that project habitat change out to 2025, based on back-casting, were also used to address conflicts about causes and trends in habitat loss. In the *Protected Area* case study, tools included trips on country with government staff, elders and MG youth; MG ceremonies to welcome people onto country; giving of skin group names (classificatory relationships) to key people; preparing and eating meals together; joint exercises in burning country/fire management; and participatory mapping.

The tools to manage knowledge asymmetries connected with, highlighted and helped to mediate the diversity of views encountered within each of the case studies. In the *Water Resources* case study artwork about the freshwater eel connected Aboriginal people's focus on stories with the ecologists' focus on assets and flow dynamics. The *Habitat Planning* scenarios helped build consensus between participants that real estate development on the coastal strip was the biggest cause of habitat loss. These various approaches allowed the diverse world views underpinning the knowledge asymmetries to sit alongside one-another, fostering mutual respect and accessibility.

4.1.2. *Institutional diversity and fragmentation*

All case studies mobilised institutions at various scales, from local through regional, State, national and international; and across a number of domains including environment, agriculture and tourism. For example, in the *Water Quality* case study, Terrain NRM worked with local farmers to change agricultural management practices. Across the 35 GBR catchments, government agencies and NRM groups co-developed monitoring, which resulted in the Reef Report Cards for measuring progress towards Reef Plan targets including the rate of farmers' uptake of practice changes. These helped leverage financial support for farmers to change practices (Australian and Queensland Governments, 2013, 2014). In the *Protected Area* case study, an informal "planning task force" between senior public servants in Perth and key regional actors ensured that the Yoorrooyang Dawang Joint Planning Guidelines were adopted as a State-endorsed policy, and that legislative change occurred to legitimise the power-sharing in park governance that was under way (DPW, 2013). In the *Habitat Planning* case study, the local Action Committee provided information to senior public servants in both State and national governments. This resulted in new national government guidelines to protect cassowary habitat, a new State planning instrument restricting real-estate development in cassowary habitat, and prohibition of one planned development in a key corridor. In the *Water Resources* case study, the Aboriginal art workshop helped trigger a larger regional study of Aboriginal knowledge, which influenced the dry season flows established in the Water Resources Plan. These mobilisations promoted institutional coherence rather than fragmentation.

4.1.3. *Uncertainty*

We defined uncertainty according to the two-part framework of Mastrandrea et al. (2010): probabilistic uncertainty based on quantitative, statistical measures; and confidence, based on the type, amount, quality, and consistency of evidence and the degree of agreement. We considered only uncertainty in the latter sense. We found that two different domains of this uncertainty were actively managed in some case studies: (1) *knowledge uncertainty* reflecting confidence in the validity of a finding (particularly a cause-effect relationship), based on the type, amount, quality, and consistency of evidence and the degree of agreement; and (2) *practice uncertainty* reflecting confidence that the benefits of a particular course of action will outweigh the risks (Mastrandrea et al., 2010; Pert et al., 2010). *Knowledge uncertainty* was lowered by overcoming knowledge asymmetries, as discussed in Section 4.1.1. *Practice uncertainty* was lowered by stakeholders taking action together even where knowledge uncertainty remained high. For example, in the *Protected Area* case study, government and MG field staff were able to work together to undertake fire management on the ground, despite ongoing differences between them about the best fire regimes for protecting biodiversity values. In the *Water Quality* case study, stakeholders resolved uncertainty about 'what should be done' by working on multiple fronts. For example, they worked on the locally appealing issue of river bank erosion as well as on precision nitrogen management to address diffuse nutrient pollution risks, even though agreement was not reached about the relative importance of protecting locally-held values compared to the "Outstanding Universal Values" that underpin the GBR's World Heritage status (Kroon et al., 2009). In both cases the benefits of working together become more evident to collaborators where time and resources enabled them to expose and debate each domain of uncertainty and develop mechanisms to handle it.

4.1.4. *Power imbalances*

In one case study, the *Water Quality* planning process, unequal knowledge – power dynamics were further entrenched when powerful actors did not collaborate with others engaged in development of the Tully Murray WQIP, and held up approval for it. Other experiences were different. In the *Protected Area* case study, the prior process of negotiating the Ord Final Agreement (see Section 3.3) had brought the MG group together to meet the WA Government on a government-to-government basis, rather than government-to-stakeholder basis, engendering greater equity, despite the underlying threat of compulsory acquisition of MG lands if negotiations failed. The perspective of equity was further empowered through collaborative planning: MG and WA Government perspectives were placed side by side as the dual platform for management, again reflecting a government-to-government approach. The Reef Partnership for *Water Quality* secured two successive multi-year investments totalling $300 million dollars to support uptake of water quality management practices and systems by farmers, empowering them for practice changes (Australian and Queensland Governments, 2013). The *Habitat Plan* collaboration was successful in achieving legal action and financial investments by State and Australian governments to protect habitat. In the *Water Resources* collaboration, knowledge partnerships that specifically addressed empowerment of Aboriginal participants through the co-production of knowledge were ranked higher than those that assumed that all participants had equal access to resources and knowledge (DPW, 2014; Robinson et al., 2015). Our analysis indicates that power imbalances were redressed through these mechanisms rather than being entrenched.

4.1.5. *"Invisible" slow-changing variables*

The *Protected Area* and *Habitat Planning* case studies showed new awareness of the impacts of slow-changing variables indicating the capacity of collaboration to address at least some dimensions of their 'invisibility'. In the *Habitat Planning* case study, the threat-based scenario to 2025 made collaborators much more aware of the trends of incremental habitat loss and ongoing degradation. In the *Protected Area* case study, the WA Government, which had committed in the 2005 Ord Final Agreement to share power over the parks in a manner that was not permitted by the legislation in place at the time, finally changed its legislation appropriately in 2012 (DPW, 2013). In the intervening years, trips onto country by MG people and their government partners overcame knowledge asymmetries about history, exposing all collaborators to the oral history of the violent contact era and its living presence in MG peoples' minds. The collaboration became recognised by collaborators as situated in the context of the relatively slow-moving variable of post-colonial reconciliation between Aboriginal and non-Aboriginal Australians (Hill, 2011).

4.1.6. *Socio-economic marginalisation and disadvantage*

No examples of entrenching marginalisation or socio-economic disadvantage were apparent in the case studies. The *Water Quality*, *Water Resource* and *Habitat Planning* case studies all brought greater prominence to Aboriginal actors who were relatively marginalised in the biodiversity issues at stake. In the *Protected Area* case study, additional resources were mobilised to provide long-term staff accommodation to a local MG person, addressing their socio-economic disadvantage, whereas previous government policy had only allocated such accommodation to people who did not live locally at the time of appointment.

4.2. *Outcomes for biodiversity conservation institutions*

We identified that the collaborations mobilised a diverse set of regulatory and incentive-based institutions, at local, regional, State and national scales, responding to the threats in each case study context (Table 3). Some limited positive outcomes for biodiversity itself had also been reported but primary data on the actual state of the biodiversity were not re-analysed.

Collaborations revealed their generative power by mobilising institutions at a scale where they had comparative advantage for impact on biodiversity. In the *Habitat Planning* case study local planning controls were not effective against habitat losses caused by powerful real estate development actors. Collaboration involved actors from national and State governments who secured the enactment of higher order and more powerful regulatory controls. In the *Water Quality* case study, change in farm practice was achieved by national government action to fund incentives for farmers to adopt these changes. Altruism alone would not have driven adoption, given the costs to farming enterprises. Recognised for its effectiveness, the Partnership Committee now sits alongside the Independent Science Panel, the Intergovernmental Operational

Table 3 – Biodiversity conservation outcomes and influences across the case studies.

Case study	Relevant institution and its influence on the key threat	Scale/s of institutional impact	Outcomes for biodiversity
Habitat Planning	Development control under Environment Protection & Biodiversity Conservation Act; Statutory Regional Plan (Sustainable Planning Act)	National, regulatory; State, regulatory	Habitat clearing prevented in critical corridors; also some funds for restoration; biodiversity loss slowed but ongoing
Water Quality	Incentives for changes to farm practices to control pollution in run-off; funded by Australian Government under Reef Water Quality Protection Plan	Farms and farmer practices	By 2013, many farmers (49% sugar cane, 74% diary, 59% horticulture) had adopted the practice changes required to reduce diffuse pollution (Australian and Queensland Governments, 2014), but overall reef health continued to trend downwards (Brodie et al., 2013)
Protected Area Co-management	Resources for on-ground management of fire, weeds and pests provided by State government	Sub-catchment scale, protected areas and adjacent lands in tributaries of the Ord River	In 2014, collaborative approaches to fire, weed and pest management were reported as having improved environmental condition in the Ord parks (DPW, 2013, 2014)
Water Resources	Water allocation under the Wet Tropics Water Plan for one water-dependent asset with Aboriginal cultural value	Regional scale under State-level legislation	No assessment available

Committee and the GBR Ministerial Forum, in the GBR governance system (Australian and Queensland Governments, 2013). In the *Protected Area* case study, collaboration mobilised resources for a level of on-ground management that was beyond the capacity of local actors. In the *Water Resources* case study, an intimate collaboration led to Aboriginal values of the freshwater eel, the focal species in the collaboration, being well identified in regional scale planning under State legislation for environmental flows (Maclean et al., 2015). This would have been highly unlikely if the standard public comment processes had continued as the sole mechanism to identify Aboriginal values – this approach had engendered a constructive-conflict rather than consensus-building response from key Aboriginal actors (Maclean et al., 2015). Collaboration did not however provide for environmental flows for a range of other species that have Aboriginal cultural significance (DNRM, 2014). Nor did it provide for Aboriginal cultural flows even though the latter have been identified elsewhere in Australia as supporting conservation of biodiversity in ways that are not within the scope of standard environmental flow prescriptions (Finn and Jackson, 2011).

However while collaboration had these positive impacts, with evidence of slowing biodiversity loss, declines in biodiversity have not stopped, as indicated in Table 3. Moreover the *Habitat Planning* case study failed to secure the institutional changes achieved through collaboration: Australian and Queensland governments had weakened the regulatory habitat protections by 2014, although further change by the Queensland government in 2015 has renewed some commitment to habitat protection.

5. Discussion and conclusion

Our analysis confirms that collaborations enable active management of many risks identified in landscape-scale biodiversity and ecosystem management. Attention to knowledge-sharing for addressing knowledge asymmetries through use of boundary objects, enhanced multi-stakeholder peer review processes, and innovative tools such as interactive spatial platforms, participatory mapping and Aboriginal-driven planning underpinned effective management across several categories of risk. Knowledge-sharing activities were central to managing institutional fragmentation, for example through the local *Habitat Planning* committee providing information to a national regulatory agency, and the *Water Quality* partnership developing effective Report Cards. Knowledge-sharing was also deployed to manage uncertainty, in concert with approaches that supported practice-sharing, such as MG and government staff undertaking fire management together in the *Protected Area* case study region.

Much of the debate in the scientific literature about the effectiveness of collaboration has focused on it as a form of decentralised governance, empowering community-based approaches as an alternative to the commonplace top-down, command-and-control, regulatory approaches of national governments (Wyborn and Bixler, 2013). Our analysis identifies that collaboration connects across scales, between top-down and community-based approaches, and between regulatory and incentive-based approaches to biodiversity conservation. These cross scale interactions produce a form of network governance. In such contexts, Cash and Moser (2000) recommended utilisation of scale-dependent comparative advantage. Our cross-case study analysis has highlighted how collaboration enables such advantage by mobilising institutions at scales that are targeted to the biodiversity action required. Collaboration coordinates the allocation of resources, technical expertise, and decision-making authority to best capitalise on scale-specific capabilities.

Our analysis points to knowledge-sharing activities as a key strategy that mobilises scale-dependent comparative advantage of institutions. Collaborative governance has the primary advantage that it is not locked into any particular scale, unlike national, state and local government jurisdictions, and can accommodate multiple issues in decision-making. The processes by which collaboration leverages knowledge can provide for both the horizontal and vertical knowledge-sharing that is needed for effective risk management (Mauelshagen et al., 2014). The capacity of collaboration to mobilise *scale-dependent comparative advantage* confirms the need to shift away from theorising about the ideal-scale for governance (Daniel et al., 2013). Scientific attention should focus instead on understanding how knowledge-sharing activities within existing multi-scalar networks can more effectively connect environmental threats with the most capable institutions to address those threats.

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