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ENVIRONMENTAL MANAGEMENT & CONSERVATION | RESEARCH ARTICLE

A research process and criteria–indicators framework for developing indigenous freshwater ecosystem health monitoring

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Abstract: Indigenous Australians' rights, interest and priorities for water management are currently recognised only to a limited extent in Australian water management policies and decision-making processes. Research has demonstrated that water monitoring based on the values, knowledge and interests of indigenous communities has empowered them in negotiating greater involvement in water management. We hereby present a case study focused on developing water monitoring that is an expression of an Indigenous Australian community's interests and vision for management. The monitoring system takes the form of a set of criteria and indicators for freshwater ecosystem health. From the case study, we derive a research process aimed at developing similar criteria and indicator frameworks for water monitoring applicable in other collaborative community-based water monitoring research initiatives.

Subjects: Biodiversity & Conservation; Culture & Development; Ethnography & Methodology

Keywords: indigenous environmental management; water quality monitoring; indigenous knowledge; traditional ecological knowledge; collaborative research; Wet Tropics; water management; ecological indicators; biocultural indicators; action research; water quality

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Frank Royee is an elder of the Malanbarra and Dulabed Yidinji community. He is passionate about protecting country and passing his knowledge down to community's youth. He has worked relentlessly all his life to guide his clan in regaining control of their ancestral land and to further their involvement in the local NRM.

PUBLIC INTEREST STATEMENT

In Australia, indigenous people have experienced dispossession and forcible removal from their ancestral land during colonisation. Losing their land and their traditional livelihoods has been a very traumatising experience for all Indigenous Australians. Despite so, many are fighting back to regain control of their land. In 1994, the law recognised for the first time indigenous land rights in Australia. Since then, many communities have been recognised as the country's legitimate traditional owners. What many of them want, is to have a say on how natural resources are used in their ancestral lands. In this paper, we describe our work with one community of Australian traditional owner. We worked with this community to prepare a water monitoring programme based on their knowledge and what they consider important. We, hope, to support the community struggle to be considered more in how water is managed in their ancestral land.

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1. Introduction

In Australia, indigenous freshwater values and knowledge are included in water planning only to a limited extent (Goode, Irvine, & Iguana, 2003; Jackson, 2005; Jackson, Finn, & Featherston, 2012; Nursey-Bray & Arabana Aboriginal Corporation, 2015; Trigger & Mulcock, 2005). Indigenous Australians place distinctive values on water: they derive their own sense of identity (Toussaint, Sullivan, & Yu, 2005) and in some cases believe they were "once" in the water, and from there they were born as humans (Gratani, Sutton, Butler, & Bohensky, 2016); in general, they maintain that water gives life to the people, plants and animals living on a specific water country[1], and that, therefore, living beings belong to water countries (Gratani et al., 2016; Grice, Cassady, & Nicholas, 2012; Maclean & Bubu, 2011; Toussaint et al., 2005).

Indigenous Australians value waters also for their economic value: resources, such as fish, prawns and crayfish, are regularly extracted for consumption (Gratani et al., 2016; Jackson et al., 2012), and the underexplored value of this subsistence economy is believed to be high, especially for people relying on welfare payments (Barber, Jackson, Dambacher, & Finn, 2015; Busilacchi, Russ, Williams, Sutton, & Begg, 2013; Jackson, 2005, 2012; Maclean & Bana Yaralji Bubu, 2011; Maclean & Robinson, 2011; Toussaint, Sullivan, Yu, & Mularty, 2001, 2005). Water bodies also offer the opportunity to generate wages via indigenous cultural and natural resource management (ICNRM) activities (Gratani et al., 2016; Grice et al., 2012; Robinson et al., 2016); cultural tourism and aquaculture; and extraction of bush tucker and medicine (Altman & Jordan, 2008; Gratani et al., 2016; Grice et al., 2012; Jackson et al., 2012; Maclean & Bana Yaralji Bubu, 2011; Morgan, Strelein, & Weir, 2004). Despite their importance, indigenous values remain under-represented in water planning and management (RAPA, 2011).

Participatory water planning and management can have a number of advantages. It can increase the well-being of rural populations, support the preservation of resources that depend on the knowledge of native communities, and empower communities to take part in management (Garcia & Lescuyer, 2008). Community-based monitoring systems support participatory water planning and management (Garcia & Lescuyer, 2008; Heaslip, 2008; Hermansen, 2010; Nursey-Bray & Arabana Aboriginal Corporation, 2015; Townsend, Tipa, Teirney, & Niyogi, 2004) as they foster ongoing consultations with indigenous groups, create opportunities for documenting water issues at local level; create tangible means by which other stakeholders can "see" indigenous values, interests and aspirations for management; and can be integrated with scientific monitoring and management frameworks, strengthening them (Nursey-Bray & Arabana Aboriginal Corporation, 2015).

Indigenous knowledge (IK)-based water monitoring systems are seldom utilised. Traditionally, indigenous communities monitored "signs" of environmental conditions and consequently adapted resource management which aimed for sustainability (Gratani et al., 2016; Jackson, 2005, 2012; Maclean & Bana Yaralji Bubu, 2011; Toussaint et al., 2005). Lore regarding what "signs" to monitor, how to interpret them, and how to consequently adapt the management of water resources was—and still is—cultural knowledge bestowed across generations through practical demonstrations and storytelling (Berkes, 2012; Berkes, Colding, & Folke, 2000; Gratani et al., 2016; Jackson, 2005; Toussaint et al., 2005). In post-colonial Australia, however, customary environmental monitoring of freshwater is not regularly conducted, one of the reasons being that legal provisions to foster indigenous water planning have been made only recently (NWI, 2004). Moreover, the extension and implementation of Native Title legislation to water resources has been slow (Tsatsaros, 2013). Finally, there is a supremacy of science-based monitoring systems, to the detriment of IK-informed approaches (Gratani, Bohensky, Butler, Sutton, & Foale, 2014).

Interest in indigenous water monitoring research has increased in Australia in response to the need for better inclusion of indigenous interests, values and knowledge expressed by the National

Water Initiative (NWI, 2004). Nevertheless, we could find only three published case studies of freshwater monitoring activities involving indigenous communities in Australia. In one case, the project focused on eliciting an IK-derived monitoring system (Nursey-Bray & Arabana Aboriginal Corporation, 2015); in the second, indigenous rangers were trained to implement a scientific monitoring programme (Tsatsaros, Brodie, Bohnet, & Valentine, 2013b); in the third, IK-derived environmental indicators were validated in a scientific fashion (Ens, Towler, Daniels, & The Yugul Mangi Rangers and the Manwurrk Rangers, 2012). Our project aims at building on these previous studies to outline a research framework for the design of water monitoring programmes that support the integration of indigenous and scientific perspectives.

In contexts other than water management, the preparation of criteria and indicators frameworks based on indigenous values and knowledge has represented a valuable medium within which social values merge with scientific knowledge of environmental conditions to monitor and influence trends in management (Adam & Kneeshaw, 2008); hence, we decided to adopt a criteria and indicators approach to our research problem.

In the Wet Tropics, water monitoring has thus far been focused on the biophysical aspect of water health (Arthington & Pearson, 2007). Current monitoring is scientifically based, focuses on water quality, and aims at quantitatively measuring nutrients, microalgal growth, water clarity, dissolved oxygen, pH, salinity, toxicants in sediments and faecal coliforms (QLD water quality guidelines, see DEHP, 2009). Recently, macrophytes' coverage, macroinvertebrates and fish have been identified as biological indicators (Arthington & Pearson, 2007). Such an approach is reductionist and keeps environmental, social and economic capitals distinct (Darnault, 2008). Our project aims to find some harmony amongst such divisions.

2. Study area

2.1. Wet Tropics World Heritage Area

The project was conducted in the Goldsborough Valley of the Mulgrave–Russell catchment in the Wet Tropics of northern Queensland. The Wet Tropics were designated a World Heritage Area (WTWHA) in 1988 on the basis of the bioregion's outstanding biocultural diversity (Hill, Cullen-Unsworth, Talbot, & McIntyre-Tamwoy, 2011; IUCN, 1988).

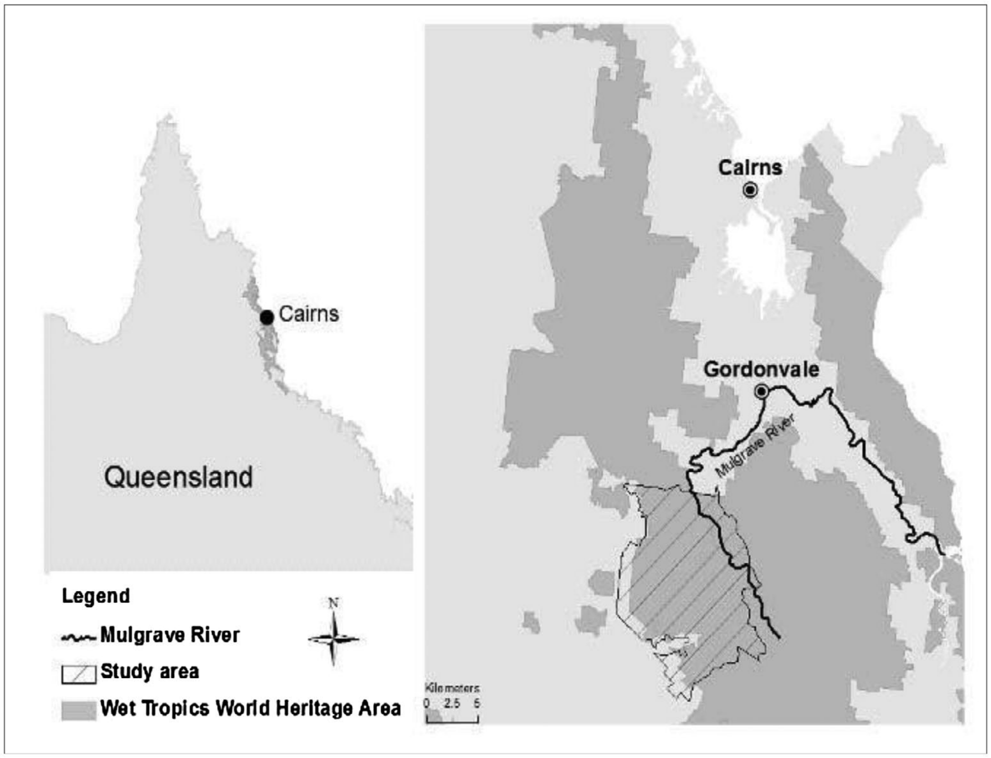
2.2. Pressures and threats to freshwater ecosystems

The Wet Tropics' rivers face numerous threats. Human population is rapidly growing in the area (WTMA, 2012), driving increased water extraction for household consumption (Cairns Regional Council, 2009). Reduced dissolved oxygen, acid sulphate soil runoff, weed infestation, reduced and degraded riparian vegetation and river flow reduction and modification are already impacting local waterways (Tsatsaros et al., 2013a; WTMA, 2002). Moreover, the presence of the exotic and highly invasive tilapia (*T. mariae*) threatens the Mulgrave River's particularly rich fauna (Burrows, 2009; Halliday et al., 2001; Webb, 2007) and concerns the local traditional owners (Gratani et al., 2011; WTMA, 2007). Finally, the river system appears to be particularly vulnerable to water flow reduction, and its healthy riparian vegetation is an important component of the native fish community's diet (Pusey, Arthington, & Read, 1995a, 1995b).

2.3. The Malanbarra and Dulabed Yidinji

The Malanbarra and Dulabed Yidinji (MDY) people are the traditional owners of the lower Mulgrave River. The language name for the MDY traditional estate is *Bulmba Malanbara*, known also as the Goldsborough Valley, and this area is located between the Atherton Tablelands and the Mulgrave River (Figure 1). Traditional main campsites used by the community were at the lower end of the Goldsborough Valley opposite Toohey's Creek, and on the Tablelands at Warrama Bora grounds, south-east of the Lake Eacham (Nungabana, 1996). The MDY belong to the language group of *Yidinji* (Tindale, 1974). The name *Malanbarra* means "people of the stony river bed": MDY people traditionally depended on the river and surrounding rainforest resources and developed a deep knowledge

Figure 1. The Goldsborough Valley and Native Title determination area for the Malanbarra and Dulabed Yidinji community.



on how to use them (Nungabana, 1996) in the 8,000 years that they occupied their land (Lee Long, 1992).

The MDY experienced dispossession and forcible relocation in the contact era. Contemporary MDY reflected on whether they wanted to undertake cultural renewal and in 1989, with the foundation of the Malanbarra Tribal Aboriginal Corporation, they began to take action to re-awaken their traditional culture and regain control of their land (Lane-West, 1991). One of the research priorities of the corporation was to conduct a community-based and culturally sensitive environmental assessment of the Goldsborough Valley to evaluate the impact of mining, agriculture, forestry and other land use on water quality and ecology of the area (Lane-West, 1991). In the MDY's vision, such environmental assessment would facilitate the community's own management of the traditional estate and would support negotiations for joint co-management with local government agencies (Lane-West, 1991). Our collaborative research project addresses this priority.

Since Native Title recognition, the Malanbarra community has established a Prescribed Body Corporate (PBC) to administer the determination area. The PBC represents today the main engagement and governance structure of the community.

3. Water and environmental governance in the Wet Tropics

The incorporation of indigenous water interests and knowledge in water management is a key hurdle for policy-makers in Australia. A legal framework to further indigenous people's inclusion in water planning and management exists (NWI, 2004), but has limitations (Tan & Jackson, 2013). However, local water governance does not currently achieve social justice (Durette, 2008; Howitt, 2001; McLean, 2007; Tan, 2009), recognition of Native Title (Jackson, 2005) or indigenous economic values (Altman, 2004; Gratani et al., 2016). Moreover, the Wet Tropics traditional owners' engagement in water planning is often ineffective and results in an unsustainable transaction cost for communities (RAPA, 2011). Structured engagement methods could support traditional owners' participation in NRM (Gratani et al., 2011), and indigenous driven water monitoring programmes could offer one such path.

4. Project design

In this context, we began a research project, initiated by the Malanbarra and Dulabed people, which aimed to understand their values and priorities for management, assess the conditions of their traditional estate, and indicate priorities for management and restoration in their traditional estate. We also wanted to initiate a path for the prompt inclusion of these values and results in the NRM decision-making processes of the Wet Tropics, which we identified in a criteria and indicators framework for water health monitoring. We therefore aimed to design a monitoring tool that was grounded in community values and worldviews, could communicate their priorities for management and could also offer a platform for integration with ongoing scientific monitoringin the area.

We started our project by building a collaborative research environment for knowledge exchange (Gratani et al., 2011), by identifying some of the constraints and enabling factors to the inclusion of IK in NRM (Gratani et al., 2014) and by understanding the values that the community places on their water Country (Gratani et al., 2016). During interviews, it emerged that some community members continue customary environmental monitoring; hence, the leading author suggested that the condition assessment and prioritisation for management could be expressed in the form of a criteria and indicators framework linked to a scoring system.

At the start of our research, in 2009, there were no published studies of collaborative water monitoring based on IK in Australia. We therefore based our research on the work of Townsend et al. (2004) in New Zealand, who formulated a Cultural Health Index (CHI) for river health that included a set of IK-derived indicators organised in a cultural component, a resource harvest component and a biophysical component, to account for the different ways Maori value riverine environments. Indicators were then scored on scales from one to five, with one expressing a poor state for the indicators and five a good state. Notwithstanding the guidance offered by Townsend et al. (2004), we allowed for the community's assessment to evolve independently, with the result that our framework is unique expression of the participant community's vision (Gratani et al., 2014).

5. Research process

5.1. Grounded theory and action research

The research was conducted within grounded theory and participatory action research methodologies. Grounded theory is a social science methodology developed to acknowledge that the emergence of new perspectives and understanding around a research problem is grounded in the actual data collected in the field without pre-conceptions that might emerge from mainstream perspectives (Strauss & Corbin, 1998). Grounded theory also provides freedom in using different data sources, such as non-academic words and actions, one's own participant observations, the literature and more structured data collection (Strauss & Corbin, 1998). This flexibility allows for the serendipity typical of research in indigenous contexts. Therefore, while the data for this project were mostly collected through semi-structured ethnographic interviews, the lead author also conducted participant observations during fieldwork. Consistent with grounded theory's reiterative cycles of data collection and analysis (Charmaz, 2008), we allowed for a revision of the research plan to account for emerging field evidence and input provided by project participants.

The iterative cycle of data collection and analysis also matched the plan–act–observe–reflect spiral of action research. Action research is a philosophical stance towards the world, an attitude of enquiry that enables researchers to explain a phenomenon through questioning taken-for-granted ways of thinking and acting in order to trigger positive social change (McNiff & Whitehead, 2009). Collaborative participatory action research enables participant communities to become prominent actors in building a fresh perspective on the researched problem and in achieving change, rather than being the object of the research (Moller et al., 2009). With this project, we wished to empower the participant communities in the management of their estate, according to their own wishes and research agenda. We included participant community members as equal co-researchers, and devolved control of the research project to them, in an attempt to decolonise our research methodology (Tuhiwai Smith, 1999). Our research can be considered "action research" in that is aims to challenge the status quo of exclusively scientific water monitoring established in the area These research modes also allowed for the incremental sharing of knowledge adopted by many indigenous communities in Australia (Muller, 2014) and elsewhere (Moller et al., 2009).

For community engagement, we followed recent Australian guidelines for participatory research with indigenous Australians (AIATSIS, 2011). Furthermore, we applied a framework developed during prior research in the area (Cullen-Unsworth, Butler, Hill, & Margules, 2008; Cullen-Unsworth, Butler, Hill, & Wallace, 2010). Regular presentations were given at the community board of directors and to participant elders, who approved our understanding of their values and indicators, and authorised and co-authored the present publication. The continuous input and cultural review process by the participant community ensured the credibility, transferability, dependability and conformability of our research (Lincoln & Guba, 1985; Nursey-Bray & Arabana Aboriginal Corporation, 2015).

5.2. Data collection

Our methods for data collection were a mix of interviews (24 members of the community), participant observation during field trips, photographic documentation and collaborative field trips, which we conducted with some key informants to the project (7 member of the participant community). Interviews were informal and mostly conducted while walking or spending time on country, the traditional estate of the community. Frequent collaborative field trips were required for key participants to recall their knowledge correctly and for the leading author to understand their perceptions of the environment. Spending time on country also allowed respect for local cultural protocols, because this is how knowledge of country is traditionally produced and transferred. When visiting country was not possible, interviews were conducted at a location chosen by participants.

5.3. Study sites

Field trips were conducted at 10 study sites selected by key participants. Selection criteria for the sites were that: (1) they were examples of "good" and "bad" environmental conditions, according to participants; (2) they were accessible to non-community members and could be surveyed within the time and budget limits of the project; (3) the legitimate traditional owners, who could speak for that area were involved in the project. One dedicated trip to women's sites, where only women accompanied the leading author, was conducted, while no exclusively men's sites were selected by participants. We do not report the locations of the study sites because the community regarded these to be culturally sensitive information.

5.4. Criteria and indicators

To develop an IK-based criteria and indicators framework, we built our conversation with project participants around the questions: "What do you *look at* in the environment to say that Country is sick or healthy?" and "Why is this important to *look at*?" The expression "look at" was used to align our communication with expressions commonly used by research participants. While the wording of the question may have lead participants to describe "visual signs" in the environment more than other signs, the criteria and indicators do not reflect such bias because participants conferred a more general meaning to the expression "to look at" when referring to the environment, rather than literally "looking with your eyes". Also, data collected through the interviews were triangulated with participant observation, informal discussions and frequent visits to country conducted for the entire duration of the project, further limiting biases.

In their responses, participants reported "signs" or indicators and then provided one main reason why an indicator was important, as well as secondary reasons. From the justifications we derived the criteria. We then ascribed each indicator to one or more criteria, following participants' directions.

Table 1. Extract of the scoring sheet used by key participants to score verifiers at the study sites

Verifiers	Score 1	Score 2	Score 3	Score 4	Score 5
State of burial site	Site exposed and highly disturbed	Site exposed and disturbed	Site exposed and slightly disturbed	Site exposed but not disturbed	Site not protected and access restricted
Number of spawning sites of Gula Gula	No longer present	Present but in decline	Decreased but now stable	Decreased but now increasing	Present at historical level

We understand that the terms “criteria” and “indicators” are not univocally defined in ecology. We drew our definition of criteria and indicators from the more established forest management literature, and in particular from the work of Adam and Kneeshaw (2008), whereby:

- Criterion is a category of conditions or processes by which sustainable management can be assessed (e.g. species diversity).
- Indicator is a quantifiable or qualifiable variable which can be measured and described.
- Verifiers[2] are variables that when observed periodically demonstrate trends. They can vary according to ecosystem and social situations.

After developing a set of criteria and associated indicators, we designed a scoring sheet with a numerical value (scoring one to five) associated with a qualitative assessment of the indicator, with one being *poor quality*—“country is very sick” in the words of participants—and five being *good quality*—“country is very healthy”. Each score was explained in words on the scoring sheet so that participants could attach a meaning to the number. For example, the indicator “state of burial site” was scored based on how the site was exposed and disturbed (the verifier was the degree of exposure and disturbance of the site), while the indicator “Spawning sites for Gula Gula” was scored based on the number of remaining spawning sites (the verifiers was the number of spawning sites remaining compared to historical data) (Table 1). The scoring sheet was then trialled in the study sites by key participants. The score provided for the different sites was averaged to provide a single numerical expression of the status of that site. The process we followed for the preparation of the criteria and indicators framework is summarised in Figure 2.

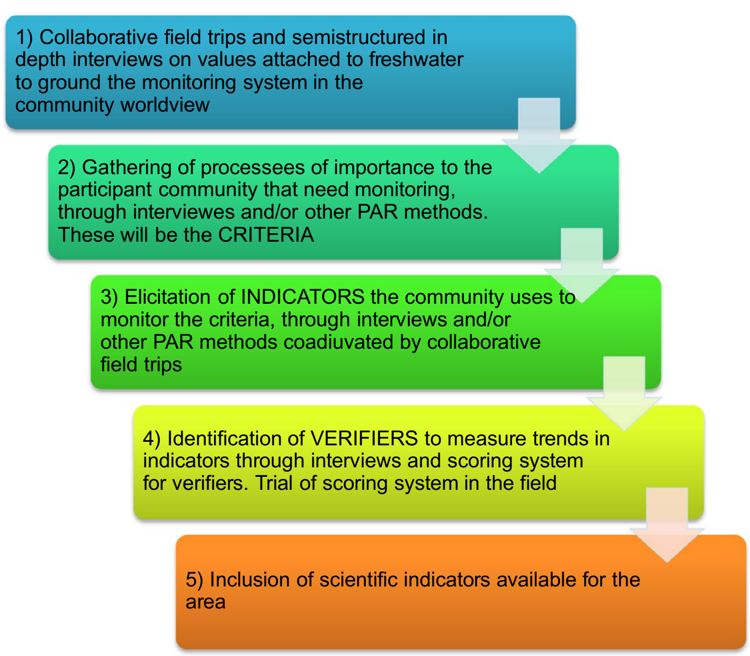


Figure 2. Process for the preparation of an integrated indigenous knowledge and science freshwater monitoring system.

6. Results

Overall, we collated a set of 40 indicators. When participants discussed the reasons why indicators were important, we were able to relate them to six main processes operating in the environment and valued by the community, which were our *criteria*. Indicators and criteria discussed by project participants are summarised in Table 2.

While each indicator was ascribed to the relevant criteria on the basis of its core reason of importance referred by participants, there was considerable overlap between indicators and criteria. For example:

- One indicator, the plant Lomandra, was listed for two criteria: cultural and traditional resources.
- Three indicators, cherry tree, freshwater crayfish and freshwater shrimps, which were used mainly to monitor the "status of traditional resources" were said to have a secondary role in monitoring water quantity, water quality and erosion.
- Three indicators, garfish, water nuts and mites under stones, were listed mainly as being related to water quality, but also represented traditional resources or were directly used to identify potable water.
- Three of the most biophysical indicators, river bank erosion, riverbed conditions and cassowaries, were said to have cultural and traditional resources implications, e.g. riverbank erosion threatens burial sites along the river, while deterioration of the riverbed increases turbidity, which in turn threatens fish populations.
- Cassowaries are now locally extinct in the study area, but participants wished to retain the indicator to express their disappointment with the loss of this important cultural keystone species.

Indicators for monitoring water quality were numerous. Water quality is paramount for the sustainability of the river system and its enjoyment through direct and indirect water use, such as drinking and swimming. One example of water quality related indicators is *Murigi*, the larvae of aquatic insects found beneath submerged stones in the river. Key community participants lift river stones to check for the presence of Murigi to decide if water is safe for drinking. Thus, the presence of Murigi is an indicator of good water quality. Similarly, the garfish, *Arramphus sclerolepis*, once abundant in the Mulgrave, was considered an indicator of good water quality and its disappearance in recent times is associated with water quality deterioration.

Project participants also discussed "pressure indicators". The main reasons of concern for pressure on the environment stemming from human activities were the introduction and spread of invasive species, unregulated tourism and four-wheel driving and upstream land use change for its potential to increase sediment, spread invasive plants and discharge chemicals downstream, especially during flooding events.

In averaging scores for the ten study sites we found that two sites, Budu Maju and Yet Foy, scored poorly, while four, Fisheries, Gulun, Jibbalan and Wotchull/Kearney's scored average and three, Japan, Miura Maraji and Mankul Women's place were considered in good condition (Table 3). It follows that, in the opinion of the participant community, Budu Maju and Yet Foy are the sites that most urgently need restoration activities in the area.

It was not possible to score the Fishery Bridge Women's place because the women of the community had not been there for decades prior to our field trip, and felt they did not know the place well enough to evaluate it. Visits had stopped due to the site being very difficult to reach unless

Table 2. Indicators and criteria monitored by participants of the Wet Tropics case study

	Criteria	Indicators used by participants
1	Conservation status of cultural and spiritual places	Burial sites
		Shield tree
		Healing places
		Fish traps
		Story places
		Birth places
		Presence of Lomandra, *Lomandra longifolia*
2	Species abundance and richness: ecological species of cultural importance	Spawning sites for Gula Gula, possibly *Acanthopagrus sp.*
		Cherry tree, *Syzigium tierneyanum*
		Yellow wattle, *Acacia flavescens*
		Glory vine, *Entada phaseoloides*
		Black bean, *Castanospermum australe*
		Freshwater crayfish, possibly *Cherax quadricari-natus*
		Freshwater shrimp/prawns, possibly species of *Caridina* and/or *Macrobranchium*
		Windin—bottle brush, *Callistemum viminalis*
		Brush turkey, *Alectura lathami*
		Goanna, *Varanus varius*
		Fungus, possibly *Balanofora fungosa*
		Cassowary, *Casuarius casuarius johnsonii*
		Interbred dingoes
		Good fishing spot
		Medicinal plants
3	Trend in water quality	Garfish, *Arrhamphus sclerolepis*
		Beetle, possibly *Gyrinidae* and/or *Notonectidae*
		Water nuts, unidentified
		Murigi, larvae of aquatic insects found under stones in the current water
		Green moss, possibly *Ectropothecium zollingeri*
		Ribbon seaweed, *Vallisneria* spp. Sediments
		Presence of sediment in the water
4	Trend in riparian habitat	Erosion of riverbank
		Coverage of riparian vegetation/Shade
5	Long-term changes in the river: riverbed and flow	Riverbed condition
		River flow
		Water quantity
6	Pressure from human activities on the environment	Unregulated tourism
		Rubbish mainly left by tourists
		Cattle
		Invasive fish
		Invasive plants
		Invasive terrestrial animal (brumbies, deer, pigs, dogs, cats)

Table 3. Scores attributed to study sites by participants

Study site no.	Site name	Score
1	Budu Maju	1.8
2	Fisheries	3.0
3	Gulun	2.9
4	Japan	3.4
5	Jibbalan	2.9
6	Miura Maraji	4.1
7	Wotchull/Kearney's	3.0
8	Yet Foy	2.6
9	Mankul Women's place	3.4
10	Fishery Bridge Women's place	N/A

permission was granted by the local land owner, whom traditional owners do not wish "disturbing". Hence, the knowledge about that cultural site was being lost.

7. Discussion and conclusion

The aim of our project was to develop a criteria and indicators framework for water management that was collaborative, representative of the indigenous worldview and that offered a context for integration of indigenous and scientific knowledge. We wanted such framework to make sense to the participant community, and to be useful to support indigenous advocacy for more inclusive water management. The resulting framework is grounded in the environmental values and world-view of the participants, and highlights that the community values and monitors six main processes (criteria) in the environment: the conservation of cultural and spiritual places, significant species abundance and richness, trend in water quality and riparian habitat, long-term changes in how the river flows and the pressure exerted on the environment, mostly ascribed to disturbance from human activities. Associated with the six criteria are numerous indicators. This ensures a robust monitoring system, with a built-in degree of redundancy that further strengthens its capacity to detect changes in the environment.

We suggest that the framework, presented in a general version in Figure 3, is applicable to other indigenous communities and has international relevance once adapted to the local context and

Figure 3. The criteria and indicators framework for IK-derived freshwater monitoring programmes.

	Criteria	Indicators used by participant community
1	The conservation status of cultural and spiritual places	**Places of importance to community**
2	Species abundance and richness	**Ecological species of cultural importance** **Usage indicator**
3	The trend in water quality	**Biophysical indicators of water quality**
4	The trend in riparian habitat	**Physical indicators of erosion** **Coverage of riparian vegetation**
5	Long-term changes in the river: riverbed and flow	**Riverbed condition** **River flow** **Water quantity/level**
6	The pressure from human activities on the environment	**Pressures identified in the area** **Pest species**
#	Others	**Others**

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different freshwater environments evaluated. Moreover, the framework lends itself to the addition of scientific indicators that need to be monitored.

We suggest that IK-derived indicators should be termed “biocultural” rather than “cultural”, as in previous research. The reason for this is at least threefold: firstly, once labelled as such, indigenous “cultural” values and knowledge can too easily be compartmentalised and thus marginalised in water planning, to the advantage of social values and biophysical science-based perspectives of the environment (Jackson, 2005). Secondarily, the term “cultural” is inaccurate for IK-derived indicators, because it conveys an expectation that the indicators are only about cultural places or cultural aspects of the landscape, while in reality they are also about water quality, sediments, vegetation cover and species occurrence and abundance, as our project demonstrated. As such, IK-derived indicators can be adopted to monitor biological and biophysical variables and processes in the landscape, in addition to cultural ones. Finally, the term “biocultural indicators” conveys a much needed synthesis of nature and culture (Maffi & Woodley, 2010).

In many ways, our results parallel those obtained by Nursey-Bray in her case study with the Arabana people (Nursey-Bray & Arabana Aboriginal Corporation, 2015), since we also found that the community monitors fauna, flora, water quality and soil characteristics; participants were comfortable in talking about “sites” to express their vision, rather than talking about “types of water”; water was always looked at in a holistic way, and always included surrounding environments (e.g. forests or riparian habitat, an aspect that is particular tricky to reconcile with current NRM policies that increasingly tend to look at land and water as separate entities (Davis et al., 2015); and absence was a dimension that was important to monitor as well as presence. In our case it was the absence of a local cultural keystone species (Garibaldi & Turner, 2004), the cassowary, whose presence in the area is acknowledged in traditional lore maintained by the community (Gratani et al., 2016).

Unlikely Nursey-Bray and Arabana Aboriginal Corporation (2015), however, indicators that our project participants proposed were applicable to all the study sites we visited, and to the entire river system. Should the framework be extended to monitoring sites further away from the river, however, the sets of indicators should be broadened. Similarly, our framework has the potential to be extended to other communities, but should be validated by the legitimate traditional owners, and modified to reflect their own vision of country, as also recommended by Nursey-Bray and Arabana Aboriginal Corporation (2015).

Environmental management should be based on best available science, and this may create the expectation for IK to be scientifically validated before being applied to environmental decision-making (Gratani et al., 2011, 2014). Our results highlight that the MDY’s criteria and indicators monitor many of the key issues identified by scientific research in the study area (Tsatsaros et al., 2013a): water quantity and quality, pest species, loss of riparian vegetation and increased sediments with more strictly cultural aspects of the landscape. Furthermore, some of the biocultural indicators monitored by the community strongly align with the biological indicators suggested by Arthington and Pearson (2007) for the Wet Tropics streams (Arthington & Pearson, 2007). For example, the indicator Murigi highlights how the community shares the scientific perspective that good water quality is associated with the presence of macroinvertebrates.

Nevertheless, some of the scientifically derived indicators for the area were not monitored by the MDY, such as the risk of acidification from sulphate soils, and concentrations of nutrients, herbicides and nitrogen. Such parameters are important in current water quality monitoring regimes for Queensland (Tsatsaros, Brodie, Bohnet, & Valentine, 2013a), and therefore they need to be included in water monitoring programmes. While we agree that IK does not always need scientific validation, we also recognise that integrating scientific indicators within an IK-derived criteria–indicator framework may make it more robust and acceptable to the current NRM community, and promotes the indigenous worldview. If kept under indigenous control, this process is not disrespectful (Gratani et al., 2011) and can lead to successful funding applications by adding credibility to indigenous stances, ultimately increasing the participation of indigenous people in NRM (Ens, Finlayson, Preuss, Jackson, & Holcombe, 2012; Tsatsaros, 2013).

Project participants often mentioned their interest in conducting water quality analyses in addition to their customary monitoring. Previous research in the Wet Tropics has demonstrated the feasibility of a scientifically rigorous water quality sampling regime to be implemented by trained indigenous rangers (Tsatsaros et al., 2013b). In our vision, these quantitative measures of water quality parameters could be coupled with the qualitative observations that community members already conduct, so as to embed scientific indicators in a fundamentally IK-derived criteria and indicators framework. In this way, indigenous ownership of the monitoring programme and empowerment in its deployment can be supported, while maintaining scientific rigour.

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Notes

1. Country has a special value for Indigenous Australians, as discussed by Ross (1996), p. 8: "Country is multi-dimensional – it consists of people, animals, plants, dreamings, underground, earth, soils, minerals and waters, air … People talk about Country in the same way that they would talk about a person: they speak to Country, sing to Country, visit Country, worry about Country, feel sorry for Country, and long for Country".
2. In our work, we used also the notion of verifiers, as showed in Table 1, to detect trends in indicators, however, for brevity, we hereby focus our discussion on the design of the criteria and indicators only.

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