Indigenous biocultural knowledge in ecosystem science and management: Review and insight from Australia

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Abstract

Worldwide, environmental conservation directives are mandating greater inclusion of Indigenous People and their knowledge in the management of global ecosystems. Colonised countries such as the United States of America and Australia have responded with an array of policy and programs to enhance Indigenous involvement; however, balancing Indigenous and non-Indigenous priorities and preferred methods is a substantial challenge and much progress has been ad hoc. Using Australia as a case study, we argue that with more strategic direction to enhance the recognition of Indigenous People and their knowledge, ecosystem science and management could greatly benefit. Focussing on the terrestrial environment, this innovative review paper aims to increase broader uptake of Indigenous biocultural knowledge (IBK) by conducting a spatial, temporal and content analysis of publically available, documented IBK materials. A spatial analysis of the place-based resources identified Australian IBK hotspots, gaps and opportunities for further collaboration. A temporal analysis of IBK material showed exponential growth in documented IBK material since the 1970’s. Indigenous authorship remained negligible until the 1990’s. Working through Australia’s ecosystem science priorities, we demonstrate how IBK has and can be used to inform research and management of fire, threatened species, invasive species, aquatic ecosystems and climate change. Lastly, we synthesise documented suggestions for overcoming cross-cultural awareness and communication challenges between Indigenous people and biologists, environmental managers and policy makers. Overcoming these challenges through development of inclusive strategies geared towards building socio-ecological resilience will guide more informed and sustainable management of global biocultural resources.
Keywords

Indigenous ecological knowledge; Traditional Knowledge; cross-cultural ecology; biocultural diversity; socio-ecological systems; sustainable development

1. Introduction

Indigenous knowledge systems contain a deep understanding of the forces that have shaped the diversity and condition of past and current environments (Gadgil et al. 1993; Berkes 1999; Drew and Henne 2006). The potential contribution of Indigenous knowledge to contemporary ecosystem science and management is irrefutable; the complex challenge we face worldwide, is how to mesh the knowledge, preferred methods and inclusion of Indigenous and non-Indigenous Peoples to reach local to international environmental and cultural conservation objectives. In recognition of this significant challenge, many international and national agencies and agreements focussing on environmental conservation, such as the Convention on Biological Diversity, the United States of America Environmental Protection Authority’s Tribal Science Council (1999) and the Australian Environmental Protection and Biodiversity Conservation Act 1999, similarly advocate for enhanced engagement of Indigenous societies in respect of their rich environmental knowledge, land ethic and the need for more equitable benefit sharing (Langton and Rhea 2005; Sachs et al. 2009). Notably, these authorities place much responsibility upon wider society to create inclusive approaches to biodiversity conservation and sustainable use of the world’s resources. Biological diversity is increasingly being linked to cultural diversity, suggesting that combined biocultural resources are integral to the survival of life on Earth (Harmon 2007; Maffi and Woodley 2010; Hill et al. 2011a). Consideration of biocultural assets as well as biological assets will elevate the role of Indigenous Peoples in broader conservation agendas.

Globally, Indigenous Peoples are recognised as a disadvantaged group and they tend to disproportionately rely on direct access to natural resources for cultural maintenance and survival (Eversole et al 2005). Therefore, inclusion of Indigenous knowledge and People in environmental conservation pursuits must consider extant power imbalances as well as cultural differences in ways of knowing and doing. Discussions between Indigenous and non-Indigenous people about culturally specific and more holistic development aspirations in relation to the environment is required to devise approaches that meet local needs (endogenous development; see Rist et al. 2011) as well as national and international obligations.

Australia has made substantial progress in building Indigenous-focussed conservation initiatives from local to national scales that aim to serve both environmental and cultural objectives. Currently, about 30% of Australia is legally recognised as Indigenous owned land, with another approximately 45% under land claims, shared or co-management arrangements (Grech et al. in prep). The Australian Government has provided increasing support for Indigenous land and sea management through the Working on Country and Indigenous Protected Area (IPA) programs. The IPA program is based on voluntary declarations of Aboriginal owned land to the National Reserve System (NRS) where the land owners are remunerated for continued management of land according to IUCN guidelines (Szabo and Smyth 2003). To date, 52 IPAs have been declared in Australia, adding over 36 million hectares to the NRS which equates to 4.75% of the continent (Australian Government 2013).

Australia’s national biodiversity conservation strategy is stratified and assessed through the NRS’s Interim Biogeographic Regionalisation of Australia (IBRA) which was developed to ensure comprehensive, adequate and representative protection of the nation’s biological resources. There are 89 IBRA regions, with conservation prioritised for IBRA regions that have less than 10% protected in reserves (including IPAs). Government obligations to meet the 10% target gave support to the IPA program as some bioregions are entirely owned by Aboriginal people (Langton and Ma Rhea. 2005). Therefore, IPA’s offer local to international benefits by contributing to Australia’s international conservation commitment (the Convention on Biological Diversity) and providing land management funding opportunity to Aboriginal People. At the local scale, hundreds of community-driven
Indigenous natural and cultural resource management (INCRM) enterprises have emerged over the last few decades as a result of increasing legislative support for Aboriginal land ownership and self-determination. INCRM has recently been described as the fastest growing sector of Australia’s conservation effort (Hill et al. 2013).

Despite achievements in Australian INCRM, there are widespread cross-cultural tensions in the planning, governance and preferred types and methods of on-ground activity. These tensions are largely attributed to the lack of understanding of alternative Indigenous knowledge systems by mainstream society and the continual privileging of ‘Western’ scientific approaches (Langton and Ma Rhea 2005; Barbour and Schlesinger 2012; Hill et al. 2013). These tensions are correspondingly reflected in the disproportionately low funding and resourcing for INCRM (Hill et al. 2013). For example, the recent Australian Government funded Terrestrial Ecosystem Research Network, made of up Australia’s most eminent ecologists, has largely ignored the large proportion of Indigenous land ownership and wealth of Indigenous knowledge in their development of a national long-term ecological research and management strategy (Ens et al. 2014). Lack of Indigenous involvement, and social dimensions more broadly, are also evident in other international Long Term Ecological Research Network’s, such as in the United States of America and Europe (Ohl and Swinton 2010).

The challenge for contemporary Indigenous people is how to maintain biocultural knowledge, customary obligations and livelihoods in the future amidst increasing pressures from dominant society to conform to ‘Western’ modes of living and environmental conservation. Aboriginal elders recognise the challenge of maintaining their cultural identity in the face of these changes:

*People. They can’t listen for us. They just want money. Money. We want goose, we want fish. Other men want money. Him can make million dollars, but only last one year. Next year him want another million. Forever and ever him make million dollars. Him die.*

*Million no good for us. We need this earth to live because we’ll be dead, we’ll become earth. This ground and this earth, like brother and mother.*

*Trees and eagle. You know eagle? He can listen. Eagle our brother, like dingo our brother. We like this earth to stay, because he was staying for ever and ever. We don’t want to lose him. We say ‘Sacred, leave him.’*

Bill Neijdje, Bunitj clan (Neidjie 2002)

A major challenge for the wider Australian population (and other nations) is to understand the crucial enabling factors that are required to facilitate self-determination and endogenous development - the development that is generated by the community for the community (Rist et al. 2011; Van der Ploeg and Long 1994). To achieve this, there needs to be greater recognition by non-Indigenous people of the value and diversity of non-scientific knowledge systems operating within society. Senior Custodians of Australian IBK emphasize this:

*...we believe that our traditional knowledge has not been recognised. However we need to be engaged and take full control of our heritage. Goal is to protect our lore and custodial rights for the future generation, which has been passed down from ancestor’s knowledge.*

Tropical Indigenous Ethnobotany Centre Advisory Board (personal communication)

### 1.2 Indigenous biocultural knowledge and Western ecological knowledge

Indigenous biocultural knowledge (IBK) is a modified phrase for what is widely known as *Indigenous Ecological knowledge* or *Traditional Ecological Knowledge*, with an emphasis on the importance of cultural connections. Gerry Turpin, *Mbabaram* Traditional Owner, co-author of this
paper, describes Indigenous biocultural knowledge as ‘knowledge that encompasses people, language and culture and their relationship to the environment’.

Interconnectedness is also a feature of the ‘Western’ scientific discipline of ecology, which is defined as the study of the interactions within the environment, and includes sub-disciplines including human and fire ecology. Considering these overlapping areas of interest in holistic and interactive knowledge systems, it is surprising that integration of ‘Western’ ecology and IBK has not been more common (Bohensky and Maru 2011).

Worldwide, IBK (or its equivalent) has long been touted as valuable to conservation science, policy and management (Agrawal 1995; Berkes 1999; Gadgil et al. 1993; Huntington 2000). While IBK is an interconnection of bio-physical, social, spiritual and cosmological realms that are manifested through Country (for further information see Smyth 1994), ‘Western’ ecological knowledge is restricted to bio-physical entities and is rigorously bound by hypothetico-deductive methodological constraints (Agrawal 1995). The two forms of knowledge are distinct but not always mutually exclusive and they can complement each other if a diversity of knowledge systems and approaches are valued (Christie 2006; Clarke 2007; Ens 2012; Hill and Smyth 1999; Nakata 2007; Russell-Smith et al. 1997). It is also important to note that the distinctions between Indigenous and ‘Western’ science are not always clear. Neither knowledge system is static; both have been and will continue to be influenced by cultural, social, economic, political and environmental factors. The meanings of IBK and ‘Western’ science have been the subject of much debate (e.g. Agrawal 1995; Bohensky and Maru 2011; Drew and Henne 2006; Shackeroff and Campbell 2007; Wohling 2009) and will not be elaborated further here; although we acknowledge that use of these simplistic terms is not ideal but they are employed for concise delivery of our key messages.

Although IBK exists largely in oral forms held by Indigenous custodians, in many instances, this knowledge has been documented, often in collaboration with non-Indigenous researchers. This knowledge tends to be held in widely dispersed records such as private journals, linguistic dictionaries, unpublished reports, community publications, academic journal articles, books, databases, digital archives, photos and videos. Many records are not publically available or in accessible forms, and sometimes, Indigenous People themselves cannot access material about their own families due to author copyright or privacy laws. For more information about research, intellectual property issues and documentation of Indigenous knowledge’s see Nakata and Langton (2006) and Janke (2009). As a result of these complexities, this review presents a broad synthesis of publically available and accessible material intended to provide a platform to guide further respectful, collaborative documentation and use of IBK for the maintenance of biocultural resources.

Irreversible modification of the environment continues to occur at a rapid rate, with no definitive abatement afforded by ‘modern’ tools such as biological or chemical control of weeds. It is timely to review and respect Indigenous biocultural knowledge and methods that have shaped the landscape for millennia and offer highly valuable insight for more effective and sustainable management of Country (Altman et al. 2007; Howitt 2001; Howitt and Suchet-Pearson 2006).

To provide a foundation for further contributions of IBK to ecosystem science and management in Australia this paper presents:

1. Spatio-temporal syntheses of publically available Australian IBK projects involving Indigenous People;
2. A case study to demonstrate the extent to which IBK is ‘living’ and has not yet been documented;
3. An overview of how IBK has informed Australia’s ecosystem research and management priorities; and
4. A reflection on key principles for effective cross-cultural partnerships in ecosystem science and management.
2. Methodology

To be included in this review of IBK in Australia, material needed to directly address the relationship between Aboriginal people and the environment, and have involved Indigenous people. Therefore, for example, archaeological work conducted by non-Indigenous researchers alone was not included. To collect the material, author databases were searched, as well as Scott’s (2004) bibliography of Indigenous Ecological Knowledge in Australia, CSIRO’s Indigenous land and sea management database, Google searches (using terms: Australia and Indigenous/ Aborigin*/ or ethno) and a public call for contributions (via email). The list of references was separated into place-based material, reviews, methodology and related resources. Place-based materials that identified particular clans, tribes, regions, towns or homelands were attributed a ‘place-name’ and were geo-referenced (given a latitude/longitude) using the Australian Gazetteer (http://www.ga.gov.au/place-name). This enabled a spatial analysis and display of material using ArcGIS.

The following spatio-temporal analyses were conducted on the place-based literature:

i) Spatial analysis of IBK materials in relation to the Indigenous estate;
ii) Spatial analysis of IBK materials in relation to Australia’s IBRA regions;
iii) Spatial analysis of IBK hotspots and Australia’s biodiversity hotspots;
iv) Temporal analysis of IBK documentation;

We also present a case study of living knowledge based on the current work of the Tropical Indigenous Ethnobotany Centre (TIEC) in Cairns, Australia. Lastly, we conducted a qualitative content review of all collated IBK materials in relation to Australia’s ecosystem science priorities: fire, threatened species, biodiversity, aquatic species and climate change (NRMMC 2010). We assessed how these materials have informed or could inform Australia’s research and management of these issues.

3. Results

Our desktop literature search resulted in a representative list of 1325 documents that contained information on Australian IBK. Of these references, 568 were ‘place-based’, 245 contained methodological or instructional content, 255 were review materials and 267 were related resources (not directly containing IBK material). These references are available on the ACEAS IBK website (www.aibk.info).

3.1 Spatio-temporal analyses of place-based literature

3.1.1. Spatial analysis of IBK in relation to the Indigenous estate

A spatial analysis of the place-based materials against Indigenous owned land (under Native Title determinations and the Northern Territory Aboriginal Lands Rights Act 1976) and declared IPA’s is shown in Figure 1. We found that 40% of materials originated from within legally recognised areas of Aboriginal owned land and 19% from within areas declared as IPA’s.

The year of IPA declaration was not related to the quantity of available materials. For example, we found the highest number of publically available IBK materials for the Djelk IPA that was declared in 2006, some 14 years after the first IPA, Nantawarrina, was declared (1992), for which we found no publically available IBK materials. Publication of materials appeared to be largely dependent upon partnerships between Indigenous and non-Indigenous people, especially researchers. The top two published IPA’s, Djelk and Dhimurru, have long standing relationships with several Universities and government researchers (e. g. Altman 1982; Haynes 1985; Kennett et al. 1997; Griffiths et al. 2003; Smyth 2007; Hoffmann et al. 2012).
We found that 69% of the IBRA regions had at least one publically available piece of IBK material. The ‘richest’ biocultural regions (IBRA regions with the highest number of IBK materials) were the Arnhem Coast, Gulf Fall and Uplands, and Cape York Peninsula IBRA regions which are all in northern Australia (Figure 2). The bioregions which were not well represented in the publically available IBK literature were mainly in Australia’s agricultural zones and Tasmania.
Figure 2: Density analysis of place-based IBK materials in IBRA regions, showing biocultural hotspots as darker areas

Table 1: The top 15 IBRA regions with the highest number of IBK materials and suggested as biocultural knowledge hotspots

<table>
<thead>
<tr>
<th>IBRA name</th>
<th>Count of materials</th>
</tr>
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<tbody>
<tr>
<td>Arnhem Coast</td>
<td>79</td>
</tr>
<tr>
<td>Gulf Fall and Uplands</td>
<td>47</td>
</tr>
<tr>
<td>Cape York Peninsula</td>
<td>29</td>
</tr>
<tr>
<td>Darwin Coastal</td>
<td>25</td>
</tr>
<tr>
<td>Murray Darling Depression</td>
<td>21</td>
</tr>
<tr>
<td>Wet Tropics</td>
<td>21</td>
</tr>
<tr>
<td>Central Ranges</td>
<td>20</td>
</tr>
<tr>
<td>Arnhem Plateau</td>
<td>18</td>
</tr>
<tr>
<td>Dampierland</td>
<td>18</td>
</tr>
<tr>
<td>Burt Plain</td>
<td>16</td>
</tr>
<tr>
<td>MacDonnell Ranges</td>
<td>16</td>
</tr>
<tr>
<td>Tanami</td>
<td>15</td>
</tr>
</tbody>
</table>

3.1.2. Spatial analysis of IBK material in relation to Australia’s biodiversity hotspots

If we follow the biodiversity hotspot classification (Myers et al. 2000), which in Australia is based on the IBRA system, the top 15 biocultural hotspots (IBRA regions with the highest number of IBK materials) could be listed as priority regions for preserving biocultural richness (Table 1).
Comparison of these *biocultural hotspots* (Figure 2; Table 1) with Australia’s 15 national biodiversity hotspots (Figure 3) showed that the two data sets or systems were mutually exclusive.

![Map showing Australia’s 15 national biodiversity hotspots](image)

**Figure 3:** Place-based IBK materials (circles) over Australia’s national biodiversity hotspot bioregions (shaded areas).

3.1.3. IBK temporal analysis

Temporal analysis of the documented materials showed a general trend for early documentation of IBK in eastern Australia moving towards central and Western Australia and more recently building in northern Australia (Figure 4). Many of the early documents contained the observations of explorers and much of this material covered vast areas and contained snippets of IBK (e.g. Eyre 1845; Leichhardt 1847; Orton 1836). The most detailed pre-1900 place-based documents on IBK came from New South Wales (Baylie 1843; Howitt and Fison 1880), Victoria (Beveridge 1889; Cary 1899; Curr 1883; Dawson 1881), South Australia (Cawthorne 1885) and northern Queensland (Palmer 1884; Roth 1897) corresponding to early settler regions.

Following the early period of colonial ‘exploration’ by non-Indigenous authors, there was a period of early ethnography and anthropology during the first of the 20th century where much more concerted efforts to better understand Aboriginal people, customs and culture were evident. Much of the published material in this period came from several key non-Indigenous researchers: the detailed and comprehensive ethnographic work of Roth in north Queensland (e.g. Roth 1897; Roth 1910); the collaborative work of Hale, Tindale, Cleland and Johnston in southern and central Australia (e.g. Cleland 1966; Cleland and Johnston 1937; Hale and Tindale 1925; Tindale 1974); and the work of Basedow, Thompson, Mountford and Specht in Arnhem Land (Basedow 1929; Specht and Mountford 1958; Thomson 1939).
In the 1970’s there was a dramatic increase in the number of IBK publications (Figure 5) which fanned out across Australia (Figure 4). The increase in publication rate appears to be the result of many new researchers entering the field. The exponential increase in publications continued to the present with an increase in obvious Indigenous authorship from the 1990’s (Figure 5). Some notable prolific publishers dominate the IBK material of recent decades: Bradley and the Yanyuwa people (e.g. Bradley 1988; Bradley 2005; Yanyuwa families et al. 2013); Clarke (e.g. Clarke 1985; Clarke 2012); Wightman and northern Australia clans (e.g. Roberts et al. 2011; Wightman and Smith 1989); the Alice Springs CSIRO research group (e.g. Baker et al. 2001; Davies et al. 1999; Dobson 2007; Walsh and Douglas 2011; Walsh and Mitchell 2002; Young 1987); and the wet tropics research group (e.g. Smyth 1981; Hill and Smyth 1999; WTAPPT 2005; Hill et al. 2011b).

3.1.4. Temporal analysis of Indigenous authorship

Using our search methodology, the earliest material with clearly identified Aboriginal IBK custodians as authors were publications on bush medicines (Dhamarrandjai and Guyamirrilili 1979; Henshall et al. 1980; Nabarula et al. 1978). Although there was a clear shift in practice in the 1990’s to acknowledge Indigenous co-authors, to date only 14% of papers containing IBK have identifiable Indigenous authors (Figure 5).
3.2. Living knowledge case study

The previous spatial analyses suggest that for many areas of Australia, IBK has not been documented, although it certainly is not absent. Indigenous knowledge is customarily transmitted orally and is still retained, modified and used by many Aboriginal people.

The Tropical Indigenous Ethnobotany Centre (TIEC) was established in 2011 as a unique Indigenous-driven initiative established to engage, support, and build the capacity of Traditional land owner groups to maintain IBK, mainly in tropical Queensland (Hill et al. 2011b). The Centre is managed by Gerry Turpin (Mbabaram clan) and an Indigenous Cultural Advisors Working Group consisting of five members from various clans in northern Queensland (who are co-authors of this paper). The main aim of the TIEC is to record and utilise Indigenous ethno-biological and ethno-ecological knowledge for cultural use on Country. Projects include: an electronic ethno-botanical database; and seasonal indicator species information for a climate change eco-tourism enterprise. To date, the TIEC has engaged with 11 Indigenous communities through 27 established or emerging projects (Figure 6). If we consider these ‘living projects’ alongside the documented IBK material, the contribution of this small centre in only a couple of years is manifold, especially for the bioregion around the TIEC (Wet Tropics) and the pastoral lease regions of the Mount Isa Inlier and Einasleigh Uplands (Figure 7).
Figure 6: Living knowledge projects of the TIEC in relation to documented publically available literature (1: Mt Isa Inlier region; 2: Einasleigh Uplands region).

Figure 7: Number of TIEC Living knowledge projects and documented IBK materials for Queensland IBRA regions.
3.3. Contributions of IBK to Australia’s national ecosystem science and management priorities

Australia’s ecosystem science and management priorities were broadly identified in Australia’s Biodiversity Conservation Strategy 2010-2030 (NRMMC 2010) as fire, threatened species, biodiversity, aquatic ecosystems, invasive species and climate change. The following section reviews how IBK has and could contribute to these contemporary environmental issues.

3.3.1. Fire management

The IBK of fire is an outstanding example of how IBK has informed fire management in Australia (e.g. Jones, 1969; Gill and Groves 1981), particularly in northern Australia over the last few decades (e.g. Haynes 1985; Yibarbuk et al. 2001; Hill et al. 2004; Russell-Smith et al. 2009). Thirteen percent of the collated IBK material in this review directly related to fire. One of the earliest and most influential examples of IBK use in fire management is the innovative Western Arnhem Land Fire Abatement (WALFA) project in northern Australia. For over 20 years Northern Territory Government scientists and bushfire staff, the Northern Australian Indigenous Land and Sea Management Alliance (NAILSMA) and Indigenous land and sea management (Ranger) groups have collaborated to promote early-dry season burns to prevent destructive late-dry season fires, protect fire sensitive species, community infrastructure and concurrently abate carbon emissions (Russell-Smith et al. 2009). This project hinges on recreating customary mosaic burning practices which have been shared with scientists by Senior Knowledge Custodians of the region (e.g. Garde et al. 2009).

The collaboration inherent to this project was recognised with a prestigious national Banksia Award in 2011 and was the basis for the first formal carbon-offset agreement in Australia (Russell-Smith et al. 2009).

There has also been a wealth of collaborative research and application of Indigenous fire management practices in the wet tropics region of northern Queensland (e.g. Hill et al. 1999; Hill et al. 2004). Here, Senior Knowledge Custodians have worked with Indigenous Rangers and researchers to record Indigenous burning practices using audio-visual technologies and multi-disciplinary techniques to promote the benefits of customary Indigenous fire management. Participatory action research has been a key feature of this work which aims to build the capacity of Indigenous and non-Indigenous participants to better understand and manage fire using both knowledge systems. A key product of this work is ‘Yalanji-Warranga Kaban: Yalanji people of the rainforest fire management book’ (Hill et al. 2004). Following from the successes of these projects, many other Indigenous groups across Australia aspire to initiate collaborative cross-cultural fire management projects.

3.3.2. Threatened fauna

There have been some significant, albeit few, long-term documented partnerships where Aboriginal people have worked with Western scientists to better understand the distribution, ecology and status of threatened species. However, there are likely to be many more undocumented examples considering the well-known animal tracking skills of Indigenous People (e.g. Southgate and Moseby 2008).

One of the first and most publicised collaborative studies between Aboriginal people and ‘Western’ scientists was that of the declining mammals of the central Australian deserts (Burbidge et al. 1988). Aboriginal people were shown museum skins and provided information about local names, the biology and ecology and the current and past status of the animals. During this research new data were collected on the distribution, biology and ecology of many species. Recently, Ziembicki and others (2013) replicated this method and supplemented it with on-Country trips and mammal trapping with Aboriginal people in northern Australia to expand the knowledge of declining species. This ‘expert knowledge’ research has been used to inform collaborative management and planning in the region, especially for fire and feral animals.
Some linguists have also conducted research into threatened fauna when building Aboriginal language dictionaries. For example, when compiling a dictionary for the Adnyamathanha People of the Flinders Ranges, Tunbridge became interested in Indigenous knowledge of the mammal fauna which had largely disappeared following European settlement in the late 1800’s. Tunbridge’s book ‘The story of the Flinders Ranges mammals’ (1992) records detailed information on the habit, diet and behaviour of 58 species. In a review of this book in *Australian Mammalogy*, Burbidge (1992) commented on the significant range extensions of many species as well as the ‘amazing ability of Aborigines to identify mammals from skins, and to relate information about animals and places that they have never seen but which had been passed onto them by earlier generations.’ He concluded the review by stating that he hoped the book ‘would encourage others to record Aboriginal knowledge in other parts of the country, particularly knowledge of extinct and threatened species of mammals, before it is too late.’ Twenty years on there has been some continuation of this work; however, such collaborations are far from reaching their potential with progress warranting even more urgency as the threats of feral animals, altered fire regimes, disease and habitat destruction continue to decimate Australia’s small mammals and reptiles (e.g. Woinarski et al. 2007).

In terms of pro-active management of threatened species, the Anangu People of the Anangu Pitjantjatjara Yankunytjatjara (APY) Lands offer an outstanding example as they have shared knowledge and developed management approaches for the threatened Black-footed Rock Wallaby (*warru, Petrogale lateralis*) with scientists since the first biological survey in the region in 1985 (Muhic et al. 2012; Read and Ward 2011). When a rapid decline was detected in populations from 1999, Anangu have worked alongside scientists to try and protect this species. In 2007, the Anangu Warru Recovery Team was established as part of the Threatened Species Recovery Plan for the *warru*. The team, including Anangu Warru Rangers, established a breeding colony at the Monarto Zoo in southern South Australia and have recently translocated joeys back to the APY Lands into large feral animal exclosures. The Warru Rangers monitor the fence, conduct traditional burning, predator baiting and monitor *warru* populations. In 2011, the *warru* team won the National Aborigines and Islanders Day Observerance Committee (NAIDOC) Caring for Country Award for their work on this threatened species. Anangu have played critical roles in this project through their use of traditional knowledge of *warru* behaviour, preferred habitat and spiritual connections and practices (including song) to facilitate project success (Muhic et al. 2012).

3.3.3. **Biodiversity**

Biodiversity surveys that targeted species significant to Indigenous people (those used for material culture, bush tucker and bush medicine), were the earliest IBK documents produced by Indigenous authors (Nabarula et al. 1978; Dhamarrandjai and Guymirrilili 1979) and have become more common (e.g. Latz 1995; Packer et al. 2011); although, are still considered vastly under-prescribed considering that about 250 Indigenous language groups occur across Australia (McConvell and Thieberger 2006). Such studies are often described as ethno-biological, ethno-ecological or ethno-pharmacological studies. A rare example of documented detailed collaborative ethno-biological research was published by Telfer and Garde (2006) who conducted one of the most comprehensive reviews of Indigenous knowledge of several species - rock kangaroos in western Arnhem Land. This work greatly expanded the ecological literature for several species of conservation interest, including information on diet, habitat use, distribution, behaviour and predation. A feature of this work was that it involved a linguist who ensured that the nuances of local Indigenous knowledge were correctly documented. Notably, there has been a concentration of ethno-biological research in the Top End of northern Australia, largely driven by collaborations involving the Northern Territory Herbarium (e.g. Wightman and Smith 1989; Roberts et al. 2011). Much of this knowledge would have been lost as elders passed away if these records were not produced (Horstman and Wightman 2001). Surprisingly, in Australia, ethno-biological research has not featured prominently in any other State or Territory Government institution until very recently, through the TIEC (Hill et al 2011b) and Macquarie University (eg Packer et al. 2011; Gaikwad 2011; Gaikwad et al. 2011).
The prevalence of cross-cultural systematic biological surveys has increased around Australia, especially since the advent of the Indigenous Protected Area and Working on Country programs. Biological surveys range from inventories to inclusion of distributional and ecological information. For example, recently, a group of Western Australian Government biologists conducted a series of biodiversity surveys with the *Pila Nguru* (Spinifex people) of the Great Victoria Desert, which greatly contributed to the documented biodiversity knowledge of the region, including several new species to science and of conservation interest (Brennan et al. 2012). Notably, these authors reiterated that such projects can be more productive when both Indigenous and ‘Western’ knowledge and survey methods are employed and drew attention to the paucity of publically available documentation on this type of research. Clearly there are vast opportunities for more collaborative biodiversity surveys across Australia, where multiple benefits for conservation, cultural maintenance and socio-economic outcomes are possible (Moritz et al. in press).

### 3.3.4. Aquatic ecosystems

Aboriginal people have long had a spiritual and life-sustaining connection to aquatic ecosystems (Bayly 1999; Humphries 2007; Clarke 2009a), which according to Humphries (2007), is not well understood and appreciated by mainstream aquatic ecologists. An outstanding example of IBK contribution to aquatic ecosystem research and policy in Australia is the demonstration of Aboriginal occupation, understanding and use of the land and waters in the Murray-Darling Basin (e. g. Weir 2009; Clarke 2009a; Birckhead et al. 2011). This work has resulted in landmark contributions of Indigenous perspectives in large-scale water management strategies (Birckhead et al. 2011), such as the National Water Initiative (Jackson and Morrison 2007); although controversy and calls for greater Indigenous involvement continue (Weir 2009; Birckhead et al. 2011; Bark et al. 2012).

Similarly, Indigenous and non-Indigenous stakeholders have made substantial headway into promoting Indigenous water rights and customary water uses in northern Australia (e. g. Jackson et al. 2005; Altman et al. 2009; Kennett et al. 2010). Socio-economic studies on the contributions of freshwater resources to the Indigenous customary economy (e. g. Jackson 2004; Barber and Jackson 2011; Woodward et al. 2012) provide substantial evidence for the imperative to honour Indigenous people’s rights to use their ancestral Country to support wellbeing and livelihoods, especially in the absence of adequate essential service delivery to Indigenous communities by governments.

Based on the present collation of IBK materials, the majority of Indigenous contributions to aquatic ecosystem research management primarily centred on Indigenous water rights. However, by international standards, recognition of Indigenous water rights in Australia is considered poor (Durette 2008; Bark et al. 2012). Therefore, there is substantial potential to further document and expand public awareness of IBK of aquatic environments, which would certainly have positive implications for more holistic management of aquatic natural and cultural resources as well as Indigenous-driven socio-economic development opportunities related to the customary economy and eco-tourism (Altman et al. 2007).

### 3.3.5. Invasive species

There was scant publically available IBK material related to invasive species, despite great potential for Indigenous insight into their historical distributions, impacts and ecology, particularly where Indigenous people have had enduring connection to Country. The relatively limited documented IBK about invasive species primarily focused on large exotic animals (e. g. camel, buffalo and pig) and comparisons of perceptions and preferred management approaches by Indigenous and non-Indigenous stakeholders (Rose 1995; Robinson et al. 2005; Edwards et al. 2008; Trigger 2008). These studies clearly demonstrated differences in world views and are very useful for building cross-cultural awareness. Few publicly available documents went on to offer practical suggestions or guidelines for working with these differences, which are particularly necessary for co-managed areas and Indigenous land for which management is often funded by non-Indigenous agencies. A rare example was detected in Edwards et al. (2008) on extensive collaborative research in central
Australia where a structured study into management options and stakeholder perceptions of feral camels were used in decision making tools that defined a range of management suitability areas.

For invasive plants there was far less documented material incorporating IBK, and for microbial invaders, we found nothing. Of the few documented materials relating to IBK and invasive plants most related to management and preferred eradication of invasive plants (Storrs et al. 1996; CSIRO 2012; Grice et al. 2012). Several materials contained information on the positive values and uses of plants by Aboriginal people, species that ‘Western’ science call invasive or pests (e.g. Wightman et al. 1994; Smith 2000; Packer et al. 2011; Clarke 2012). Again, there is ample opportunity to expand our understanding of different world views in relation to invasive species and development of preferred management approaches that serve these alternate views.

3.3.6. Climate change

Climate change is expected to have significant social, economic and environmental impacts, particularly for Indigenous communities who are least resourced to adapt (Green et al. 2009). The predicted effects of rising sea levels and changing seasonality include: a loss of community and environmental assets, loss of cultural heritage sites, a significant downturn in the human quality of life, and the establishment of potential favourable conditions for the spread of invasive plant diseases, weeds and pests (Green et al. 2009).

There is a growing body of published literature discussing the importance of IBK and worldviews in the climate change debate (e.g. Green and Raygorodetsky 2010; Petheram et al. 2010; Alexander et al. 2011; Leonard et al. 2013), although there has been limited documented use of IBK by Australian climate scientists. Indigenous communities have long observed and recorded the phenology of flora and the seasonal behaviour of fauna through biocultural knowledge systems. Recently, many Indigenous groups across Australia have begun to document their seasonal knowledge (e.g. Hoogenraad and Robertson 1997; Clarke 2009b; Green et al. 2010; Woodward et al. 2012). IBK paradigms, as described earlier in this paper, have high levels of socio-ecological complexity that help explain the changing relationships between cycles of inter-annual weather patterns, water availability and the subsequent response of flora and fauna in the landscape. The use of seasonal calendars has the potential to highlight the Indigenous identified bio-temporal indicators of landscape response to climatic change and provide a basis for developing detailed climatic monitoring and evaluation programs (e.g. Leonard et al. 2013), particularly for the growing extent of Aboriginal owned and managed lands.

4. Discussion

Langton and Ma Rhea (2005) assert that ‘the documentation of traditional or Indigenous knowledge is fundamental to the capacity of traditional knowledge holders to promote, protect and facilitate the proper use of their knowledge’. For this to occur, IBK custodians and their communities must see the value in documenting inherited and new knowledge, understand the variety of forms that this can take as well as incumbent Intellectual Property issues (see Janke and Frankel 1998; Janke 2009). To facilitate the funding and support for IBK documentation, arguably a greater impediment is the attitude of dominant non-Indigenous society and the resultant values and priorities of funding bodies. Therefore, a shift in society’s values towards more inclusive, diverse and equitable approaches is required (Barbour and Schlesinger 2012; Ens et al. 2014). In ecosystem science and management this will require strengthening the understanding and acceptance of different knowledge systems, values and priorities to facilitate greater cross-cultural or two-way learning approaches (Marika et al. 2009; Yunupingu and Muller 2009; LaFlamme 2011; Ens et al. 2012).

The review of Australian IBK material presented in this paper is not reflective of the entire body of IBK in Australia as much knowledge has not been documented. It is also likely that the methodology deployed here did not capture all documented IBK works as many may not be publically available for
good reason relating to information sensitivities and property rights. However, an examination of publically available IBK material is beneficial as this is what is likely to shape broader community perceptions about IBK, unless people have closer connections to Indigenous people and communities. Despite these limitations, this review clearly demonstrates that IBK has and can continue to make substantial contributions to the understanding and implementation of Australia’s national ecosystem science and management priorities. The large spatial gaps in IBK documentation detected in this study illustrate vast opportunities to expand cross-cultural research, management and awareness of Australia’s unique assets to deliver environmental, cultural and socio-economic outcomes. Of particular note are the IBK material gaps in agricultural areas and Tasmania which are areas where Indigenous people suffered great disruption following colonisation.

We found that Indigenous land ownership clearly offers a stable platform for enhanced collaboration and mobilisation of IBK resources; however, has not prohibited the documentation of IBK on other land tenures (where 60% of IBK materials originated). For example, the TIEC works with many Indigenous groups in Queensland where vast tracts of land are currently held under pastoral leases and private non-Indigenous ownership. In some cases there has been great incentive to maintain and document Indigenous knowledge for the Native Title process where Indigenous ownership of Country is granted following demonstration of continuous occupation. There are also benefits to raising public awareness of the biocultural value of Indigenous owned land (including government supported IPAs) as a perceived higher value by the public and funding bodies can leverage greater investment. In support of this supposition, a recent study by Hill et al. (2013) showed that between 2002 and 2012 the Dhimurru and Djelk IPAs received the highest income of all IPA’s which corresponds with our finding that these two IPAs also had two of the highest numbers of publically available IBK materials, and therefore public awareness and arguably perceived value. This correlation between IBK material availability and income may not be causal; nevertheless, it is an interesting coincidence when considering the aspirations for culturally meaningful development of many Indigenous communities.

If we are to move beyond simple biodiversity conservation by incorporating socio-ecological systems thinking (e. g. Sachs et al. 2009) that serves to promote more inclusive conservation practice, conservation priorities could adopt our biocultural hotspot concept. Broadening the biological hotspot targets to include culture is one way of enhancing the role of Indigenous people, knowledge and land into national conservation priorities. Therefore, following the logic of Myers et al (2000) the most bioculturally and biologically rich areas ‘undergoing exceptional threats’ could be targeted for conservation. Alternatively, the gaps in IBK documentation could be considered a priority for funding and work as in these areas, IBK may be critically endangered. Decision making about biocultural asset maintenance is similar to the debates about biodiversity and threatened species conservation – do we conserve the richest ‘intact’ areas, try and maintain or increase richness in less ‘intact’ areas, or adopt a blend of approaches (Kareiva and Marvier 2003)? We acknowledge again that the ‘gaps’ identified in this study may simply be an artefact of the methodology as we only used publically available and accessible IBK materials; however this foundational work raises the question about what should or could be supported to maximise return on investment. Considering the increasing interest in Australian IBK documentation shown in Figure 6, it is timely to assess the content and geographic spread of the baseline data and look to develop a more strategic approach to managing Australia’s biocultural resources, importantly, in collaboration with Indigenous people. To do this, there needs to be greater awareness of the value of Indigenous knowledge and a willingness to accept differing knowledge systems by broader society.

4.1. Breaking down intellectual and institutional barriers

Globally, the value of ‘cultural brokers’ for negotiating divergent knowledge systems and understanding has been recognised when working in complex cross-cultural or cross-disciplinary spaces (Guston 2001). Use of cultural brokers is of particular relevance for work on Indigenous land, with Indigenous people or when using IBK (Maru and Davies 2011; Robinson and Wallington 2012).
Drawing on ‘champions’ that may be individuals or larger groups or agencies who have the power to drive institutional change may also strengthen efforts to raise awareness of the value of IBK in national conservation decision-making. The conglomerate of leading ecologists which make up Australia’s Terrestrial Ecosystem Research Network (TERN) could play a leading role in driving change and reaching out to mainstream society, in line with Australia’s Biodiversity Conservation Strategy Priority 1 – Engaging all Australians. Of all the 12 long-term ecological research projects under the banner of TERN, only one project (the Tropical Savanna project) has formally engaged Indigenous stakeholders (Ens et al. 2014). While internationally, initiatives to incorporate long-term socio-ecological research into national ecology networks like TERN are gaining momentum (e.g. Ohl and Swinton 2010).

It is clear that we need to move beyond participation to more active engagement of Indigenous people, knowledge and Country in environmental conservation initiatives (Colechester 1996; Hill et al. 2012; Walsh and Mitchell 2002). There are many examples of tokenistic and limited collaborations between Indigenous people and environmental scientists and managers. Generally, in Australia and likely in other colonised countries, the reasons for limited Indigenous involvement can be distilled down to a poor understanding of Indigenous history and culture by the wider populous and a general failure to appreciate alternate knowledge systems as a result of Eurocentric education systems. The result of dominant colonial histories has been the development of rigid environmental project and funding frameworks that tend to work against Indigenous involvement.

In Australia, key principles for effective collaboration between Indigenous and non-Indigenous people have been widely documented (e.g. Janke and Frankel 1998; Davies 2007; Desert Knowledge Cooperative Research Centre 2008; Marika et al. 2009; Davies et al. 2011; Ens et al. 2012; Hoffmann et al. 2012). In summary they are:

1. Cross-cultural awareness and sensitivity;
2. Respectful consultation and partnerships from project conception to completion and communication;
3. Enough time and adequate resources to discuss, consult and conduct the work;
4. Legal advice on Intellectual Property rights;
5. Prior informed consent of all people involved;
6. Equitable remuneration and acknowledgement of collaborator’s time and knowledge; and
7. That the principles of the UN Declaration of the Rights of Indigenous Peoples and the Australian Institute for Aboriginal and Torres Strait Islander Studies (AIATSIS) guidelines for research with Indigenous People’s be followed.

Indigenous land and sea management corporations are increasingly seeking collaboration with non-Indigenous scientists, managers and policy makers to fulfil their own research questions and organisational needs (Hoffmann et al. 2012; Marika and Roeger 2012). As Hemming et al. (2007) comment, government programs and support institutions come and go which ‘...means that universities are even more important as partner organisations for capacity building, knowledge development and knowledge exchange for Indigenous communities seeking social transformation.’ Development of respectful partnerships with long-term commitment has proven to deliver mutual, nationally significant and transformative benefits for ecosystem science and management, such as the warru and Western Arnhem Land Fire Abatement projects previously described.

5. Conclusions

Over the last two centuries, there have been large shifts in the way non-Indigenous people have engaged with Indigenous people, land and biocultural knowledge towards much more inclusive and respectful interaction, although inequitable benefit sharing remains. Many Aboriginal people still refer to Indigenous knowledge systems and Law when trying to make sense of environmental
change, despite the impacts of European colonisation. There are clear hotspots of documented IBK in Australia that have greatly enhanced the broader understanding and management of coupled natural and cultural systems. We have shown that all of Australia’s conservation priorities could be greatly informed by IBK, although the existing opportunities far outweigh the advances made to date. Threats to global environments are increasing, so it is timely to rethink our ecological knowledge base and develop more holistic and inclusive research, management and funding options for the future. Enhanced cross-cultural and cross-disciplinary engagement has great potential to strengthen global capacity to build socio-ecological resilience for more holistic, inclusive and sustainable environmental management strategies.

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