Global Environmental Change 23 (2013) 623–632

Contents lists available at SciVerse ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha

The role of culture and traditional knowledge in climate change adaptation: Insights from East Kimberley, Australia

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ARTICLE INFO

Article history:
Received 2 February 2012
Received in revised form 1 February 2013
Accepted 27 February 2013

Keywords:
Adaptation
Indigenous peoples
Culture
Traditional ecological knowledge
Worldviews
Australia

ABSTRACT

Indigenous peoples offer alternative knowledge about climate variability and change based on their own locally developed knowledges and practices of resource use. In this article we discuss the role of traditional ecological knowledge in monitoring and adapting to changing environmental conditions. Our case study documents a project to record the seasonal knowledge of the Miriwoong people in northern Australia. The study demonstrates how indigenous groups' accumulate detailed baseline information about their environment to guide their resource use and management, and develop worldviews and cultural values associated with this knowledge. We highlight how traditional ecological knowledge plays a critical role in mediating indigenous individuals and communities' understandings of environmental changes in the East Kimberley region of north-west Australia, and how these beliefs may influence future decision-making about how to go about adapting to climate change at a local level.

1. Introduction

The projected impacts of climate change on Australian ecosystems and settlements are well documented (CSIRO and BoM, 2007). More recently, several studies have suggested that Australia's indigenous communities are especially vulnerable to the impacts of climate change; in particular, climate models indicate that sea level rise and storm surges will affect Australian indigenous coastal communities (Hennessey et al., 2007). Emergent research also indicates that Aboriginal and Torres Strait Islander communities' who depend on bush or sea food for their livelihoods (both subsistence and market-based) are particularly at risk to future climate changes (Green et al., 2009). Unsurprisingly, the issue of how Indigenous communities can respond to climate change is an increasingly prominent topic of discussion amongst Indigenous communities and governments (Hunter and Leonard, 2010; Petheram et al., 2010; Sinnamon and Mango, 2010; TSRA, 2010).

Worldviews are an underappreciated element of adaptation as they shape how people understand the causes of phenomenon that can be linked to climate change, which in turn influences the acceptability of adaptation responses (O'Brien, 2009; Adger et al., 2009a,b). Each adaptation option and any decision about the governance and institutional arrangements for adaptation is underpinned by a set of values associated to particular worldviews that shape what is considered to be worthwhile adaptation action and what it not (Jacob et al., 2010; Wolf and Moser, 2011; Spence et al., 2011). Worldviews not only influence what adaptation strategies are deemed possible, but also what people considered to be a barrier or limit to adaptation (Adger et al., 2009a,b). Although this point might seem obvious, it was not until comparatively recently that researchers began to explore how worldviews and associated value systems shape adaptation in any great detail (Coulthard, 2009; O'Brien, 2009; Wolf, 2011). Research from around the world highlights how competing worldviews can result in different stakeholder groups' favouring dissimilar adaptation options and perceptions of what constitutes successful adaptation (O'Brien et al., 2009; O'Brien, 2009; Ensor and Berger, 2009; Heyd and Brooks, 2009). In coastal settings, for instance, adaptive management is increasingly a pivotal part of planning for future sea level rise and as a means to reconcile conflicting goals (Tompkins et al., 2008). However in regards to indigenous peoples there is only limited engagement with the idea that indigenous value systems may shape both the process and outcomes of climate change adaptation for indigenous communities world-wide. In this article we explore the critical role traditional ecological knowledge plays in mediating indigenous individuals and communities' understandings of environmental change in the East Kimberley region of north-west Australia, and how these beliefs may influence future decision-making about whether and

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http://dx.doi.org/10.1016/j.gloenvcha.2013.02.012

how to go about adapting to climate change. In this paper, we first provide a brief overview of recent research into traditional ecological knowledge, environmental management, and climate change. We then proceed to discuss the historic, geographic and social setting of this research as well as the methodology we adopted. Finally we outline our research findings, which are structured into three themes: specific environmental knowledge, use and management techniques, and worldviews.

1.1. Traditional ecological knowledge

In this paper we use the term traditional ecological knowledge to refer to knowledge of the environment that is derived from experience and traditions particular to a specific group of people (Berkes, 1999; Houde, 2007). Traditional ecological knowledge can be seen as both dynamic and cumulative, building on past experiences and adapting to changing circumstances. Such knowledge is commonly held collectively within a community or society, with aspects of it only known by specific members of the group such as specialists, elders, descendents (lineage) or gender groups. Moreover it is a specific attribute of societies and groups with historical continuity in resource use within a particular area or environment (Berkes et al., 2000). The majority of these are non-industrial focused societies; many are tribal or indigenous, however not exclusively. Some non-indigenous groups nevertheless hold traditional ecological knowledge (Neis, 1992, 1997).

Over the last three decades, numerous scholars have sought to understand traditional ecological knowledge and how it can inform western scientific knowledge and environmental management practices (Berkes, 1999; Berkes et al., 2000; Lantz and Turner, 2003; Moller et al., 2004; Briggs, 2005; Langton et al., 2005; Coombes, 2007; Clarke, 2009; Moller et al., 2009; Prober et al., 2011). Some have distinguished between different elements of traditional ecological knowledge which, when combined together, form the traditional ecological knowledge of a particular social group (Usher, 2000; Houde, 2007). Others take a broader, less explicit approach to traditional ecological knowledge that encompass all knowledge and practices of Indigenous or local peoples. In this article, we have grouped Miriwoong traditional ecological knowledge in three categories, which are interconnected and mutually informing, in an effort to demonstrate in a concise and simplified manner how traditional ecological knowledge can be considered in climate change adaptation strategies. Our three categories are adapted from Houde (2007) and Prober et al. (2011) see Table 1.

1.2. Traditional ecological knowledge and climate change

Increasingly researchers are turning their attention to examine the ways in which indigenous and local groups' knowledge of the environment can be used to inform climate change mitigation and adaptation, including monitoring the impacts of climate change, carbon abatement initiatives, and the development of local strategies (Ford et al., 2007; Salick and Ross, 2009; Turner and Clifton, 2009; Dumaru, 2010; Green et al., 2010). At present the majority of research efforts are directed towards the use of traditional ecological knowledge for monitoring the impacts of climate change and to inform mitigation activities. Limited attention has been given to the role traditional ecological knowledge, as part of a wider belief system, plays in shaping individuals and communities' perceptions and responses to environmental changes. In research undertaken in northeast Arnhem Land (Northern Territory, Australia), Petheram et al. (2010) note that although the Yolngu people (Aboriginal traditional owner group) were aware of climate change, they did not consider climate risks to be of primary importance to their community. Yolngu interpreted the 'strange changes' they had been witnessing over the last five years in part the consequence of inappropriate actions and land use changes including mining activities, recreational fishing and tourism rather than to global environmental change (Petheram et al., 2010). Moreover Yolngu community organisations refused to disconnect climate risk in northeast Arnhem Land from the other sources of risk they faced, most notably the endemic poverty and the absence of essential services which is characteristic of remote indigenous communities throughout Australia (Petheram et al., 2010; Howitt et al., 2011). Similarly in the international context, Byg and Salick (2009) report that Tibetan villages perceived changes in climate to be related to local phenomena, such as spiritual retribution, overpopulation, and increased electricity consumption.

In both places, people conceptualise observed climate changes as inherently local phenomena, yet ultimately attribute them to the actions of humans (either by influencing the spiritual world, or acting directly on the environment), and do not necessarily prioritise climate risks above others. Indigenous peoples' perspectives on the environment are typically defined in terms of worldviews or cosmologies, traditional ecological knowledge and associated cultural protocol form the socio-environmental relationships that link the environmental system to peoples' identities, attachments to places, livelihoods, histories, economic and political contexts (Donner, 2007; Wolf, 2011). The challenge is how to incorporate the multiplicity of climate change narratives into community-based plans and projects to enable successful adaptation. This challenge is particularly significant in the context of indigenous rights and knowledges in Australia because of the long history of paternalistic colonial and postcolonial policies and practices. This resulted in Australian Aboriginal and Torres Strait Islander communities being managed as simultaneously needy and problematic populations requiring external control and the risk remains that similar

Table 1
TEK classification systems.

TEK categories (Houde, 2007)	TEK categories (Prober et al., 2011)	TEK categories (this article)	Miriwoong TEK discussed in this article
Factual observations	Basic knowledge of the environment	Environmental knowledge	• Classification of weather conditions • Seasonal indicators • Observations of climate variability and change • Water availability
Management systems Past and current uses	Knowledge of Aboriginal use and management of the environment	Use of biodiversity resources and management of environment	• Fire management • Harvesting activities • Water way management • Biodiversity monitoring
Ethics and values Culture and identity Cosmology	Knowledge Frameworks	Worldview	• Ethics and values • Cultural identity • Adaptation options

approaches will be adopted in climate change adaptation planning (Howitt et al., 2011).

2. Background

The Kimberley region, located in the North West of Australia, extends northwards from the Great Sandy Desert to the tropical savannas of the Kimberley Plateau and its coastal islands and east to the Northern Territory border (see Fig. 1). The region covers an area of 424 500 km^2 and is nearly two times the size of the state of Victoria in Australia's south east (Masini et al., 2009). The climate of the Kimberley, like elsewhere in Northern Australia, is largely tropical monsoonal, with annual rainfall highest near the northern coast and decreasing towards the arid interior. The majority of rainfall occurs between December and March, with little rainfall from May and October. Temperatures are high year round but generally peak in December through to March. Archaeological records from the Kimberley are extensive and evidence suggests continuous occupation since about 40 000 years BP in coastal regions (McConnell, 1998).

Despite its large geographic size, the total population of the Kimberley is only 35 000 people, the majority of whom live in the region's six towns (Broome, Derby, Fitzroy Crossing, Halls Creek, Wyndham, and Kununurra) (Australian Bureau of Statisics, 2006). In addition there are more than 100 remote Aboriginal communities spread across the Kimberley. Nearly 80 per cent of the permanent population of the Kimberley is of Aboriginal or Torres Strait Islander descent, and the region is one of the most culturally and linguistically diverse geographical areas in Australia, with twenty-seven traditional Aboriginal language groups found within its boundaries. Not only do Aboriginal people comprise a large proportion of the population of the Kimberley, they are also significant landowners with Native Title rights or interests applying to at least 90 per cent of the region (NNTT, 2012). In the present day, however, there is a pattern of persistent Aboriginal disadvantage in the Kimberley, wherein Aboriginal individuals, families and communities are faced with widespread poverty, deficient health and educational outcomes, an adult mortality rate which is 10–12 times higher than non-Indigenous Australians, and an incarceration rate 15 times the national average (Biddle, 2009; Anderson et al., 2006).

In this article we focus on the Miriwoong people, whose traditional lands encompass the floodplains of the Ord and Keep Rivers, and the township of Kununurra. The traditional lands of the Miriwoong people extend from Carlton Hills Station in the north, Lake Argyle and Ord River in the south, and Keep River in the East (Pursche, 2004). These lands transcend the state boards of Western Australia and the Northern Territory and are subject to complex state government legislation and land tenures ranging from freehold Native Title Lands', pastoral leases, jointly managed conservation areas and a National Park (Leonard, 2010). The majority of the Miriwoong people now live in or near Kununurra, the name a white misinterpretation of the Miriwoong name Goonoonoorrang meaning 'river', which is the largest settlement in the East Kimberley (population 7000) (Hill et al., 2008). Kununurra was established in the 1960s as part of the Ord River Irrigation Area (ORIA) scheme, which saw the construction of a diversion dam along the Ord River, created an artificial lake (Lake Kununurra) and established of a small area of irrigated agricultural land (Head, 1999). Following on from this another larger dam (Ord Dam) was constructed 55 km upstream from the diversion dam, which was completed in 1972 and resulted in the flooding of approximately 98 000 ha of land within the domains of the Miriwoong and Gajerrong peoples to create the storage reservoir of Lake Argyle (Pursche, 2004). The dams were used to provide irrigation to more than 10 000 ha of land; in 1996 a hydro-electric power station was

Figure 1: General map of the Kimberley region

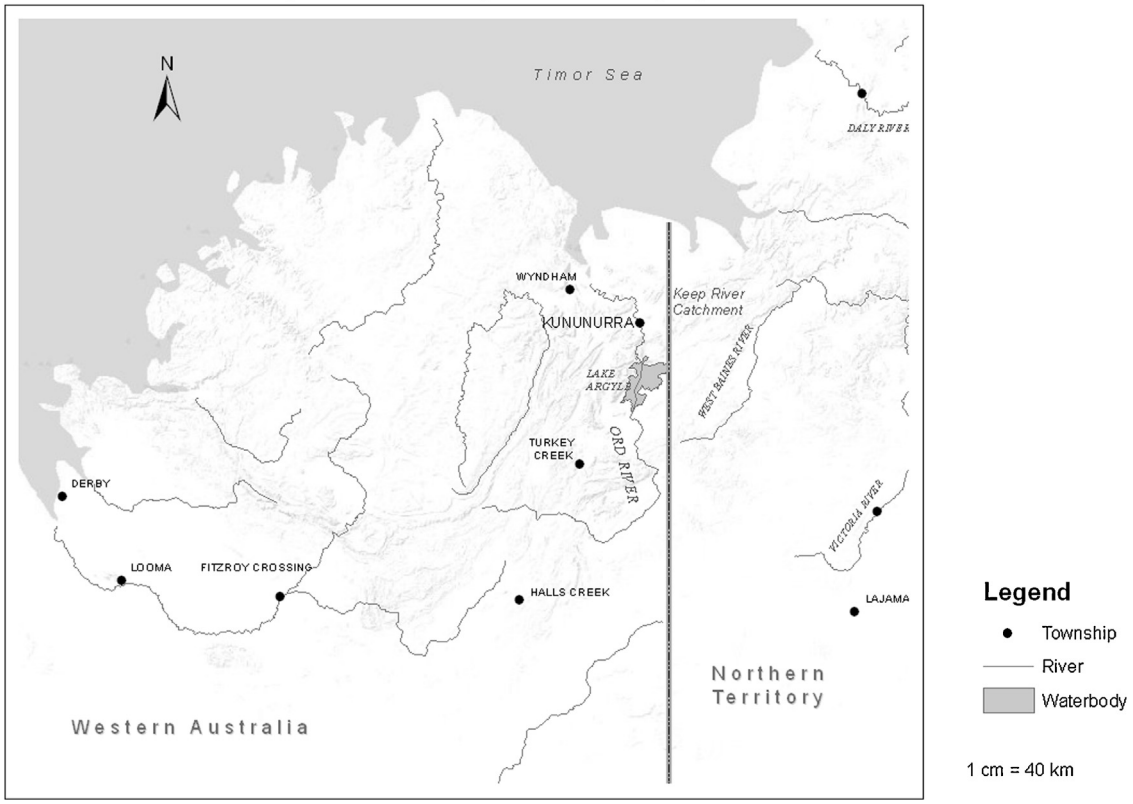

Fig. 1. General map of the kimberley region.

added to the main dam, and irrigation activities were expanded on the Ord River floodplain. Stage one of the Ord irrigation scheme had lasting social, cultural and environmental impacts. Miriwoong people recall that the diversion dam was built on an important story place (Darram), and the dams flooded countless burial areas, rock art sites, and meeting places (Hill et al., 2008). In addition the Ord scheme fundamentally altered the terrestrial, freshwater, and riparian ecosystems along the Ord River by preventing seasonal flood events, trapping fauna in upstream, and altering the availability of water (Masini et al., 2009; Head, 1999).

3. Methodology

This study draws on ethnographic research carried out in Kununurra and Keep River, East Kimberley between May 2008 and June 2011. Research was carried out in East Kimberley as part of ongoing research into Indigenous ecological knowledge, environmental change and local governance arrangements by researchers from the Mirima Dawang Woorlab-gerring Language and Culture Centre and the University of Melbourne. Research was directed by Sonia Leonard (University of Melbourne), who was based in the Kimberley and was funded through grants derived from the Indigenous Community Water Facilitator Program of the Northern Australia Indigenous Land and Sea Management Alliance, and the Bureau of Meteorology. Field sites were chosen in response to gaps identified through consultation with Miriwoong traditional owners and the Mirima Dawang Woorlab-gerring Language and Culture Centre. The research design used a mixed method approach, including individual and focus group interviews with Miriwoong people, participant observation, oral history recordings, and archival material.

The project was initiated through the Mirima Dawang Woorlab-gerring Language and Culture Centre allowing community members to be involved in the research design from the outset. Participants became involved on the basis of self-selection based on personal interests and willingness to discuss the topics; recommendations by elders; or by existing relationships with researchers.

We employed narrative inquiry (Table 2) during the semi-structured interviews with participants. The research questions were not explicitly designed to focus on climate change, but rather focused on traditional ecological knowledge and changes on the local environment. The interviews allowed for more informal discussions, the emergence of unanticipated insights, and the pursuit of specific issues that may have remained untouched in more formal research settings. During the interviews – both individual and group – participants chose to move throughout the landscape and show researchers aspects of the environment that were being discussed, and shared singing, dancing, and art work that related to topics. At a later stage, we also shared scientific understandings about hydrological and climatic systems, as well as climate change, using diagrams and photographs to illustrate technical concepts.

All interviews were digitally recorded. In addition conversations and observations during participant observation were written down in notebooks. Nine focus group interviews were undertaken, some of which were differentiated by age, and gender in line with cultural practices. Five of the focus groups were conducted in Kununurra, and other four were undertaken as part of community camping trips to the Keep River National Park. These camping trips (known colloquially as "back to country trips") involved taking Miriwoong people back to their traditional lands in the Northern Territory to camp for periods ranging from three to five days. Trips were undertaken at different times of the year to document seasonal changes. For Miriwoong people, whose lands are divided between the jurisdictions of Western Australia and Northern Territory and who live chiefly in the town of Kununurra and surrounding small communities, The practice of camping on their traditional lands (commonly referred to as 'back to country trips') is seen as both socially and spiritual important (Pursche, 2004). This process of returning to country reflects longstanding cultural practices that link the physical presence and movement of walking with the process of maintaining familial, economic and spiritual ties to the country (Toussaint, 2008). The practice of taking Indigenous groups back to their traditional lands is increasingly recognised as a key ingredient to successful community-based research into Indigenous issues in Australia (Palmer et al., 2006).

The majority of respondents were native speakers of Aboriginal Kriol and, especially amongst the older generation, Miriwoong. Interviews were therefore conducted in Miriwoong, Kriol or English, or a combination, depending on the preference of each research participant. Linguists from the Mirima Dawang Woorlab-gerring Language and Culture Centre, and translators from the Kimberley Interpreting Service, translated between English, Kriol and Miriwoong throughout all interviews and focus groups. In addition the linguists played a pivotal role in the transcription phase and sought to ensure researchers interpreted Miriwoong language words and traditional knowledge correctly.

Table 2
Selection of terms used by Miriwoong to describe weather conditions.

Weather condition	Miriwoong word
Clouds	Ngoomelng
Wind	Genkaleng
Lightning	Jimilwiring
Floodwater	Warrayalng
Rain	Jadang (noun) Jaloorr (be raining)
Rainbow	Wajiny
Thunder	Deroorr-deroorrb

4. Results and discussion

The results were structured to reflect the socio-ecological nature of the Miriwoong traditional ecological knowledge system. Our analysis of the research results according to the three dimensions of traditional ecological knowledge – environmental knowledge, use and management, and worldviews – and present Miriwoong traditional ecological knowledge in tables throughout our results for ease of reading. However the information collected during this research project was also compiled into a interactive seasonal calendar for the Miriwoong community which can be accessed through the websites of the Mirima Dawang Woorlab-gerring Language and Culture Centre and the Australian Bureau of Meteorology (see http://www.mirima.org.au/calendar/) (MLCC, 2011).

4.1. Miriwoong knowledge of their environment

For Miriwoong people the year is divided into three distinctive seasons: Nyinggiyi-mageny (wet season), followed by Warnka-mageny (cold season) and then Barndenyirriny (hot season). Each season is further differentiated into sub-seasonal weather patterns, with each sub-season associated with particular climatic conditions (including cloud formations, wind direction, rainfall, and temperatures). For instance the wet season of Nyinggiyi-mageny comprises two sub-seasons known as Barrawoondang and Jaloorr-mageny. Barrawoondang refers to thunderstorms with strong wind and lightning and is associated with Jaloorr goowinda (the arrival of rain) prior to the onset of heavy monsoonal rains of Jaloorr-mageny (see Table 3). Miriwoong Knowledge of seasons, and sub-seasons forms the hierarchy for which all other traditional ecological knowledge held within the seasonal calendar is ordered. Phenological events, such as the timing of growth, development,

Table 3
The Miriwoong seasonal calendar.

Season	Sub-season	Weather conditions	Indicators	Actions: use and management
Warnka-mageny (Cold Season)	**Genkaleng** (Start of cold) When south winds start to bellow it marks the beginning of the cold weather.	**Dengga** (Clearer weather) When the rain starts to clear up and the sky opens up. Clear days without many clouds prevail	**Gali-Galing** (Fern-leaf grevillea) *Grevillea pteridifolia* When the tree bears its bright orange flowers the Miriwoong people know the cold season has arrived	**Garrjang** (Water lily) *Nymphaea* sp. The water lily is found in many lagoons and some springs. The flowers are available year round in permanent water and appear in some seasonal waterholes during the wet season. However roots and seed are traditionally harvested only during the cold season.
			Jilginy (Freshwater crayfish) *Cherabin* When the freshwater crayfish produce their eggs.	**Gawarroong/Derrmad** (Freshwater crocodile) *Crocodylus johnstoni* The freshwater crocodile lays its eggs in the sand during this time, and Miriwoong people dig up the eggs for food.
	Werlthang (middle of cold) When dew forms overnight leaving the landscape wet.		**Wiling** (Caustic bush) *Grevillea pyramidalis* The Caustic bush grows 3–4 m high, with needle-type leaves. When the tree flowers it is an indicator that it is the middle of the cold season.	**Warralab gejawooleng** (Light fire) The time to light fires to burn the savannas. Burning helps reduce intensity of wildfires during hot season.
				Genambooroong (Spear tree) *Acacia gonclada* The time to harvest wood from Genambooroong to make spears.
	Manbilying (End of cold) When cold weather rain arrives.	**Thalmoorrjeng** (Ice mixed ran) When hail storms can occur. This weather phenomenon is now infrequent, but elders report that it was more frequent in the past.	**Warnembang** (Sugar Leaf) *Glycaspis* Sugar leaf is the local name for the honeydew (lerrp) which builds up on the leaves on eucalypt trees. Its appearance marks the end of the cold weather and the transition to the hot season.	**Gerdewoon** (Boab tree) *Adansonia gegorri* The nuts of the Boab tree are ready to be harvested at the end of the cold season. Miriwoong people roast the nuts over the fire.
Barndenyirriny (Hot Season)	**Boornbeng** (Warm up) Time when the country starts to warm up.	**Ngandoongoorroong ngararlng** (Clear sky) When the skies are clear with little cloud.	**Boornbentha dawang** The temperatures are hot.	**Thelawoong** (Long Yam) *Dioscorea* sp. The harvesting of long yams begins in the warm up period and continues through the hot season.
	Dilboong (Dried out) The country has dried out, the ground is dusty and everything is brown.	**Boowoorroogoong-goornkirring** (North wind) The north wind blows drying out the country further.	**Dabaroong** (Pelican) *Pelecanus conspicillantus* When the Pelican starts flying in certain formations it indicates the country is drying out.	**Niyini** (Double-barred finch) *Taeniopygia bichenovii* The double-barred finch is found around water sources. In the dry period, Miriwoong use the bird to help locate water.
			Goorrandalng (Brolga) *Grus rubicunda* The Brogla is a large grey bird that lies throughout the area. When the Brogla are seen flying around in circles in search of water it indicates Diboong.	**Jardang/Gajarrang** (Spinifex grass) *Triodia* The Spinifex grass is found in the foothill country. The grass is harvested at the end of the hot season, before the first rains. The grass is used to make resin.
	Deroorr-mageny (Calling of the thunder) This describes the time when the heat and humidity is building up.	**Ngoomelng** (Clouds) The build up of clouds before the rains.	**Gerdewoon** (Boab Tree) *Adansonia gregorii* When it flowers it indicates the end of the hot season and the start of the build up season.	**Garelng** (Native Melon) *Cucumis trigonus* It is time to harvest the bush melon when it turns yellow.
		Deroorr-deroorrb (Thundering clouds) The clouds that built up producing thunder	**Woolegalegeng** (Silver leaf paperbark) *Melaleuca Argentea* The flowering of the Silver leaf paperbark tree indicates the beginning of the thunderstorms.	**Jaliwang** (Barramundi) *Lates clacarifer* The Barramundi begin to breed at end of the hot season. They are a much sought after food source during this period.
		Jawoo-jawooloong (Heavy rain) Heavy rain that accompanies thunderstorms but lasts only a short time.		

Table 3 (*Continued*)

Season	Sub-season	Weather conditions	Indicators	Actions: use and management
Nyinggiyi-mageny (Wet Season)	**Barrawoondang** (Time of strong wind, thunder, lightning and rain)	**Ngoomelng birrga ginayin jaloorr-gerring** Gathering of rain clouds.	**Goorrawoorrang** (Chanelled billed cuckoo) *Scythrops novaehollandiae* When the cuckoo is heard calling loudly it indicates forthcoming rain.	**Dawarrg** (Plains goanna) *Varanus* sp. The Plains goanna is an important food source. The wet season is the best time to hunt goanna because they are fat.
		Jaloorr goowinda The arrival of rain.		
		Warrayalng (First flood) The first heavy rains that cause the rivers to flow quickly, the water to turn brown, and the fish to die.	**Boodbarang** (Konkerberry) *Carissa lanceolata/spinosa* The scrub produces a small black fruit during the early wet season.	**Moonamang** (Magpie Goose) *Anseranas Semipalmata* Magpie Geese nest during the wet season around wetlands. They are hunted during this period.
			Bilbiljeng (Grasshopper) Grasshoppers appear throughout the landscape at the arrival of the rains.	
	Jaloorr-mageny (Time of rain)	**Melijegeb** (Night rain) Rain which falls heavily during the night, but stops during the day.	**Woorerreng** (Bush Yam) *Ipomoea sp* The Bush Yam plant grows in sandy country and flowers during the wet season.	**Woolewooleng** (White current) *Flueggea virosa* The white current plant grows in shady areas around rivers. The fruit of the white current is harvested during the middle of the wet season and is traditionally an important food source.
		Nyinggiyeng (Continuous rain) Continuous rain, which lasts several days, typical of monsoons.		
			Thelawoong (Long Yam) *Dioscorea* sp. The vine of the Long Yam grows tall during the wet season.	**Mejerren** (Black Plum) *Vitex glabrata* The Black Plum tree is found in hilly country and produces a small sweet fruit during the wet season which a popular food source for Miriwoong people. The fruit is harvested during the middle of the wet season.
		Walanbinang (Floods) The river breaks its banks and overflows the floodplains and low lying areas. People need to move to higher ground and be careful when travelling.		

behaviour or reproduction of flora and fauna become indicators of the annual progression through the seasonal cycles. A senior male elder and fluent Miriwoong speaker explains:

> Another indicator for the Barndenyirriny [hot season] is the pelican we call them Dabaroong. They make a corkscrew like flight, up in the sky. They start off from here, they go round like this like a corkscrew round and round and then when it find water they come down to that water ... [The pelican] look around for water now because everything dries up.

The time to collect, hunt and fish is related to the season, the associated weather conditions, and phenological events. For instance during Derorr-mageny (a sub-season of the hot season) clouds begin to gather and thunderstorms are common in the late afternoon. Miriwoong people know the thunderstorms are coming through the observation of flowers on the Woolegalegeng (silver leaf paperbark tree). The arrival of thunder intern is an indicator that Garelng (bush melon) are ready to be harvested.

This facet of Miriwoong traditional ecological knowledge consists of the identification, naming and classification of distinctive components of the environment. It contains empirical observations, and information about the behaviour and abundance of flora and fauna at particular times of the year. Miriwoong people traditionally relied on such knowledge to ensure food, water, shelter, medicines and other resources. Physical and biological events served as indicators of change and were interpreted as signals that particular actions needed to be undertaken at certain times (including the hunting and harvesting of food sources, cultural ceremonies and practices). In the Keep River, for instance, Miriwoong people observe that the flowering of the Gali-Galing (Fern-leaf grevillea) signals the beginning of the cold season and is time to undertake tradition burning practises to prevent late hot season fires that damage the landscape. Miriwoong traditional ecological knowledge consists of a set of personal observations conducted over a prolonged time period and reinforced by the observations of other traditional ecological knowledge holders. When this information is collated over annual cycles it provides the basis of the Miriwoong seasonal calendar. On the surface, the calendar may be viewed simply as a timetable that divides the year into seasons, and describes likely weather conditions and resources available. However more in-depth analysis reveals that the Miriwoong traditional ecological knowledge contains information derived from observations and adaptations to changing environmental conditions over long periods of time. In this way Miriwoong traditional ecological knowledge, like that of other Indigenous groups, offers considerable insight into ecosystem dynamics on a local level and, when coupled with other sources of knowledge, variations in climate over both geographical and temporal scales.

This aspect of traditional ecological knowledge is the one most compatible with western scientific thinking and is of interest to scientists because it may enhance scientific understandings of the dynamics of ecosystems. Miriwoong traditional ecological knowledge is not simply about the availability of resources, but also provides bio-temporal indicators that link changing climatic conditions (based on temperature thresholds, moisture levels and other environmental factors) with the behaviour of flora and fauna (see Table 3). A male elder describes the relationship between fish behaviour and seasonal variations in the Keep River:

> The Barndenyirriny [hot] time, it get warm up. At that time we get fish, it tell us that a lot of fish will be in the shade, in under the shade, like that tree leaning over the water, you know where that shade is, a lot of [fish] will be there cooling off ...

The elder makes clear the link between climatic change, temperature and the aquatic response and in doing so highlights the complexity and holistic nature of Miriwoong traditional ecological knowledge. Significantly it is only in the last two decades that Australian scientists have begun to recognise the critical part riparian vegetation plays in maintaining stable water temperatures. The shade from riparian vegetation, as the Miriwoong elder aptly summarises, reduces the temperature of water during periods of hot weather so that temperatures in shaded watercourses provide safe habitat for aquatic life (Rutherford et al., 2004).

Miriwoong traditional ecological knowledge also offers insight into the hydrological cycle and the seasonality of surface water flows within the region. For instance, the term Nyinggiyeng (continuous rain) is linked to the phrase Walanbinany balawaji girayin, which refers to the process whereby rivers experience over bank flows with floodwaters spreading out across the entire floodplain. Due to the damming of the Ord River, large floods are no longer experienced and Miriwoong people report that this has changed the pool riffle ratio of the lower Ord River and subsequent distribution of aquatic species. Miriwoong participants also report that during Barrawoondang rainfall is intermittent and Warrayalng (the first flood) occurs. The word Warrayalng does not simply refer to the first flood event, but describes the entire process in which the first sustained rainfall cause the rivers to run, the waters to turn brown, and the fish and freshwater crustaceans to die. Western scientists refer to this phenomenon as a 'black water event' wherein the accumulation and breakdown of leaf litter on the dry riverbed results in discolouration and low levels of dissolved oxygen in the water when the river begins to flow again (Gordon et al., 2004). In the East Kimberley, river systems are ephemeral in nature, which means that Warrayalng or black water events occur every year.

In the East Kimberley, scientific records of climate-related events (including extreme weather, water availability, and phenology) are limited in number and time-scale. However traditional ecological knowledge and the use of the Miriwoong seasonal calendar as a baseline from which to assess changes in climate at a local level could provide a valuable (and cost-effective) alternative to western scientific monitoring projects. Furthermore, the monitoring of small scale changes at a local level offers the potential to enhance western scientific understandings of environmental change and reduce current uncertainty about climate change models for northern Australia. Indeed Miriwoong people already use their knowledge of the local environment and anticipated weather conditions and resource availability to interpret or read their country (traditional lands) and note when something unusual or abnormal occurs. One example provided by Miriwoong people was that of 'Knock 'Em Down Rain' (a Kriol term) which is the rain that flattens the spear grass and occurs in the barrawoondang at the end of Nyinggiyi-mageny (wet season). Miriwoong associated Barrawoondang with the Walanbinang event and also consider it an indicator that the wet season (including tropical cyclonic activity) is drawing to an end. In recent years 'Knock 'Em Down Rain' was not observed and Miriwoong people expressed concern that changing weather patterns was impacting their environment.

4.2. Miriwoong use and management of environment

In addition to baseline information about the environment, Miriwoong traditional ecological knowledge also contains knowledge about the use of natural resources as well as management of land and sea country, which includes methods to prepare for anticipated hazards. Miriwoong people, like other Australian Aboriginal groups have developed a variety of strategies to cope with the climatic variability such as resource sharing, group mobility, fire management, and harvesting practices. Indeed mounting archaeological, anthropological and historical evidence indicates that Aboriginal groups possessed a high degree of resilience to environmental change and variability (McConnell, 1998; Langton, 2003; Toussaint, 2008). In the tropical savannas that comprise much of the Kimberley, for instance, the seasonal variations and distinctive wet-dry monsoonal climate were the biophysical phenomena that underpinned Aboriginal seasonal burning practices used to manage spaces for living, food, medicine and other necessities of life (Toussaint, 2008; Hill et al., 2008; Russell-Smith et al., 2009). Fire serves several purposes for Miriwoong: it flushes out animals and allows hunters to catch them more easily; it reduces vegetation density and makes the land and waterways more accessible for people and certain species of plants and animals; and it reduces the chances of larger and more dangerous fires occurring later in the year. Over the last two decades Australian scientists and natural resource managers have sought to learn from and emulate Aboriginal fire management regimes and introduce seasonal fire burning back to the tropical savannas, and seasonal burns (fire abatement) it is now an accepted method to reduce greenhouse gas emissions in Australia (Russell-Smith et al., 2009). In the East Kimberley, however, fire management regimes are incompletely applied to the landscape due to opposition from white agriculturalists, lack of government investment, and limited capacity within local Indigenous institutions (Hill et al., 2008).

Miriwoong use and management of natural resources centres on customary rules based on weather conditions and seasonal indicators contained within their seasonal calendar (see Table 3). This knowledge forms part of the Miriwoong people's traditional natural resource management (commonly referred to by Australian Indigenous groups as 'caring for country') and serves to provide prescriptions for the intensity, frequency, and timing of harvesting activities. For instance the arrival of the thunder during the hot season (Barndenyirriny) indicates that the Native Melon known as Garelng (*Cucumis trigonus*) is ready to harvest. However Miriwoong respondents suggest that climate change, in interaction with other non-climatic drivers of environmental changes (such as mining, dams, and irrigated agriculture), is decreasing their ability to predict the availability of certain resources. Miriwoong people report changes in the timing of the fruiting of the Daloong (green plum) and Mejerren (black plum) trees, which are typically available in December and January each year. In 2010 both species fruited two months later, and many interviewees reported that when they went to harvest the fruits the quantity and quality of both fruits was considerable less than in previous years. They assigned these changes in the timing and productivity of the two trees to climatic changes and reported that Nyinggiyi-mageny was considerably late and that the heavy rains never occurred. In contrast, in 2011 the wet season of Nyinggiyi-mageny was the wettest in living memory and the Aboriginal community of Warmun in the upper reaches of the Ord River catchment was severely flooded.

Such climate extremes and changes are negatively affecting the harvesting activities of Miriwoong people, and other Aboriginal groups in the Kimberley. The bio-temporal indicators used historically to determine the availability of plants and animals, and the arrival of weather events have shifted. Many Miriwoong people are concerned that their indicators of seasonal change are no longer accurate, and argued that they need to establish monitoring and evaluation programmes that assess observed changes in bio-temporal indicators to develop tools that allow adaption of traditional ecological knowledge in contemporary Miriwoong society. In addition Miriwoong elders expressed worry that the younger generation, who live chiefly in Kununurra and do

not speak the Miriwoong language fluently, do not know or appreciated the importance of Miriwoong traditional ecological knowledge sufficiently to cope with current or potential environmental conditions. The use of the Miriwoong seasonal calendar to monitor small-scale climatic changes, in addition to its potential to enhance scientific understandings of climate change, is seen by Miriwoong elders as a way to retain and communicate traditional ecological knowledge to the younger generation, and in doing so enable them to adapt their resource use and land management practices to the changing environmental conditions they encounter. The maintenance and use of traditional ecological knowledge is perceived by Miriwoong people as the most important way they can respond to environmental conditions, and is indicative of the extent to which adaptation is inherently a social process that underpins the worldview of each group or society that is adapting.

4.3. Worldviews

The final facet of Miriwoong traditional ecological knowledge discussed in this article is what we call worldviews, and others refer to as value systems (Usher, 2000), knowledge frameworks (Prober et al., 2011), and cosmologies (Houde, 2007). For many Miriwoong people their traditional ecological knowledge forms part of their belief system, and contains value statements about how things are and should be. From a traditional Miriwoong worldview, still common amongst Miriwoong elders, the environment is positioned as sentient and communicating with them, as well as ancestral beings (dreaming spirits) (Rose, 1996; Hill et al., 2008). Miriwoong people took great effort to explain the extent to which their traditional ecological knowledge is located within their culture and law. An elder explains:

> We have visited three communities so far and each one of them communities all have waterholes ... we believe they are made by our Ngarranggarni, what you whitefella call dreamtime. We have our own name for it. The dreamtime is special to us, it ties in with our land and our law and culture. That's all together, all in one big package. That includes the top surface water and the bottom half of the water. Sometimes we can't speak about it [groundwater] because it reflects back to the men's [secret/sacred] side of law and culture.

In line with this understanding of the socio-ecological relationship, Miriwoong people believe that their actions (or inactions) can affect environment (including weather conditions). Such cultural protocol, which are located within Miriwoong traditional ecological knowledge, seek to restrict certain activities (harvesting, hunting, collecting water) at particular times of the year. Incorrect behaviour is associated with spiritual retribution evident in negative outcomes such as dangerous weather conditions, a poor hunt, or physical ill health. On the flip side, the correct actions–such as singing and performing the right practices–are seen to cause positive results, including favourable weather conditions.

The general consensus of perception research about climate change suggests that people often consider climate change a remote risk, which is removed from their direct personal experiences in both space and time (Wolf, 2011; Lowe et al., 2006). For Miriwoong people the environmental changes they are witnessing are seen to be a direct consequence of the disrespectful treatment of the environment. In particular they link changes to their historical removal from traditional estates and subsequent failure to appropriately manage lands (through fire regimes, visiting waterholes, living on country and so on), as well as the consequences of mining, pastoralism, irrigated agriculture, and the damming of the Ord River. Climate change is conceptualised as tied to inappropriate actions on a local rather than global scale, connected to the arrival of gardiya (white people) and the end of Aboriginal people living on the land (as opposed to in townships). Moreover Miriwoong peoples' discussions about environmental change always related back to their experiences and knowledge of past changes within their traditional lands. For Miriwoong elders, in particular, the act of damming the Ord River, flooding large portions of their traditional lands, and pumping water away for agricultural and mining operations remains a source of deep hurt and pain for them.

This research indicates that perceptions of climate change are substantially shaped by perceptions and knowledge of pre-existing local environmental and socio-economic conditions. In the case of Kununurra, Miriwoong people are well aware that the climate and local ecosystems are changing; however they typically perceive these changes in the context of local development pressures (dams and irrigated agriculture), while interpreting some climate related impacts (such as severe floods in April 2011) as related to spiritual retribution. In this way it is difficult to separate climate from other drivers of change both in a material sense (dams, mines, and land-use changes) and in a cosmological sense (it is not just the climate but also people who cause these changes). These results raise important questions about how indigenous and non-indigenous groups' not only perceive and respond to the impacts of climate change, but also the acceptability and effectiveness of climate change adaptation strategies.

Each adaptation strategy is underpinned by a set of values that define what is considered to merit the effort of adaptation (Adger et al., 2009a,b; Ford, 2009; Ford et al., 2010; Dumaru, 2010). In the Miriwoong context, these values are related to a greater or lesser extent depending on the individual (their age, gender, lineage, knowledge, and connection with Miriwoong community), on Miriwoong traditional ecological knowledge. In this way Miriwoong traditional ecological knowledge serves to provide standards that guide individuals' decisions, choices and attitudes. For the purposes of future adaptation, these values are likely to shape what the goals of adaptation are for Miriwoong people, for instance, preserving the status quo of the Keep River ecosystem or improving the quality of life and well-being for Miriwoong community members in Kununurra. Further research is currently underway to explore the integration of Miriwoong traditional ecological knowledge into community-driven adaptation plans and options. However, based on studies of indigenous attitudes towards water planning, natural resource management and disaster management in the region, it seems that Miriwoong people are unlikely to accept externally driven adaptation options (Jackson, 2006; Toussaint, 2008; Finn and Jackson, 2011; Howitt et al., 2011). Indigenous groups throughout Australia question the efficiency of governments – and white society in general – to manage their traditional land and waterways appropriately, and reference declining biodiversity and water quality in the region as evidence of this (Toussaint et al., 2001; Hill et al., 2008; Leonard, 2010). This discontent is likely to shape their responses to externally imposed (irrespective of whether it is governmental or non-governmental) adaptation strategies and represents a potential barrier to successful and equitable adaptation in the Kimberley region as elsewhere. Whereas community-driven projects that draw on Miriwoong traditional ecological knowledge and embrace Miriwoong aspirations for increased decision-making powers over their traditional lands and waterways potentially enable adaptation in the East Kimberley context.

This will be a challenge, however, given that government engagement with contemporary indigenous governance structures remains both limited and highly prescriptive (Howitt, 2006). The existing approaches to indigenous affairs worldwide, continues to rely heavily on externally driven (top-down) measures and there is a very real risk that governments will adopt a similar approach to

climate change adaptation. Moreover key institutional arrangements continue to privilege discourses based on scientific knowledge and administrative expertise over local knowledges (including traditional ecological knowledge), and continue to diminish the social dimensions of risk in favour of 'paternalistic presumptions of what is "best" for minority groups' (Howitt et al., 2011).

5. Conclusion

We have demonstrated how three aspects of traditional ecological knowledge can contribute towards improved understandings about the impacts of climate change, and provide insight for the development of equitable and effective climate change adaptation strategies. For Miriwoong people, their traditional ecological knowledge forms part of their social, economic and cultural cornerstones, and influences individuals' preferences, beliefs, and day to day practices, and by extension their perceptions of and responses to the impacts of climate change. Indeed all people (indigenous and non-indigenous alike) by and large base their decisions on an accumulation of a diverse range of information, including both individual preferences and their cultural value systems (Wolf, 2011; Donner, 2007). Our research demonstrates that in many instances Miriwoong people are worried about the same issues as scientists, such as land use changes, water management, and weather extremes, but frame their concerns through their specific worldview. Yet even where understandings about the drivers of change are different, shared concerns offer the potential to provide common ground on which indigenous interests and aspirations for the future can converge with those of researchers, policy makers and other interested parties (Ford et al., 2007; Berkes, 2009).

People, indigenous and non-indigenous alike, are motivated by a wide range of factors which vary between individuals, communities, and wider social groups. For instance, business-focused individuals may be interested in the financial costs of a particular adaptation strategy, whereas lifestyle-orientated people may be more concerned about the aims of the strategy and how it aligns with their personal activities and lifestyle choices (Cumming and Collier, 2005; Frank et al., 2011; Marshall et al., 2011). However, as we have sought to demonstrate in this article, indigenous peoples (both in Australia and elsewhere) hold distinct worldviews often derived from their traditional ecological knowledge. This in turn helps establishes their views and responses to climate change. Of critical importance to indigenous peoples is their continued ability to access their traditional lands, harvest flora and fauna, visit and maintain cultural heritage sites, and retain their language and traditional ecological knowledge in the face of climate change, land-use change and government policies. Accordingly indigenous groups may be unwilling to enter agreements that restrict or threaten their abilities to access and maintain specific social, cultural and economic relationships with particular landscapes. On the other hand, flexible projects that can be aligned in some way with indigenous aspirations and goals for the future have a good chance of success. Goals will differ among indigenous groups, some will be directed towards economic development (cultural tourism, horticulture, aquaculture), others towards environmental management (the co-management of national parks), cultural heritage (transmission of traditional ecological knowledge or the perseveration of cultural heritage sites), or education (youth employment and training). There are numerous entry points for the development of successful adaptation strategies. The central challenge therefore for governments and service providers will be to genuinely engage with indigenous worldviews and negotiate appropriate, equitable and effective strategies to prepare for and respond to changing environmental conditions. This should involve organisations (government and non-government) identifying and working towards what the community wants to achieve rather than focusing narrowly on government policy directives.

Acknowledgements

The authors would like to thank Professor Marcia Langton, Professor Jon Barnett and Dr Fiona Miller, for their constructive feedback about this paper. Many thanks needs to be given to the Miriwoong people of the Keep River Region, NT, who have been involved in this project, and have allowed us to present aspects of their TEK to a wider audience. Additional thanks are given to the Mirima Dawang Woorlab-gerring Language Centre, the Kimberley Land Council, the Northern Australia Indigenous Land and Sea Management Alliance (NAILSMA), the National Climate Change Adaptation Research Facility (NCCARF), and the Australian Bureau of Meteorology who provided funding and staff in support of this project.

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