Ways of Knowing

The Integration of Indigenous Knowledge and Scientific Knowledge for Natural Resource Management

Student Handouts

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Assignment 1: Ways of Knowing, Definitions

Homework Assignment 1:

1. Read The Alaska Native Science Commission's definition of indigenous knowledge, excerpted below.
2. Read Wikipedia's definition of the scientific method, excerpted below
3. After you read these definitions watch: "Vandana Shiva on Mechanists vs Scientific Knowledge" https://vimeo.com/103764529
4. Watch "Science and the Scientific Method" https://vimeo.com/33295400
5. Compare and contrast indigenous knowledge and scientific knowledge using the table provided. Bring the completed chart and answers to the additional questions to class.

1. Traditional Knowledge Systems in the Arctic (source: **http://www.nativescience.org/html/traditional_knowledge.html)**

"When an elder dies, a library burns": An Eskimo hunter once saw a polar bear far off across flat ice, where he couldn't stalk it without being seen. But he knew an old technique of mimicking a seal. He lay down in plain sight, conspicuous in his dark parka and pants, then lifted and dropped his head like a seal, scratched the ice and imitated flippers with his hands. The bear mistook his pursuer for prey. Each time the hunter lifted his head the animal kept still; whenever the hunter 'slept', the bear crept closer. When it came near enough, a gunshot pierced the snowy silence. That night, polar bear meat was shared among the villagers.

A traditional hunter plumbs the depth of his intellect - his capacity to manipulate complex knowledge. But he also delves into his animal nature, drawing from intuitions of sense and body and heart; feeling the wind's touch, listening for the tick of moving ice, peering from crannies, hiding himself as if he were the hunted. He moves in a world of eyes, where everything watches - the bear, the seal, the wind, the moon and stars, the drifting ice, the silent waters below. He is beholden to powers greater than his own…"

The Director General of United Nations Educational, Scientific and Cultural Organization (Mayor, 1994) defines traditional knowledge:

The indigenous people of the world possess an immense knowledge of their environments, based on centuries of living close to nature. Living in and from the richness and variety of complex ecosystems, they have an understanding of the properties of plants and animals, the functioning of ecosystems and the techniques for using and managing them that is particular and often detailed. In rural communities in developing countries, locally occurring species are relied on for many - sometimes all - foods, medicines, fuel, building materials and other products. Equally, people's knowledge and perceptions of the environment, and their relationships with it, are often important elements of cultural identity.

Most indigenous people have traditional songs, stories, legends, dreams, methods and practices as means of transmitting specific human elements of traditional knowledge. Sometimes it is preserved in artifacts handed from father to son or mother to daughter. In indigenous knowledge systems, there is usually no real separation between secular and sacred knowledge and practice - they are one and the same. In virtually all of these systems, knowledge is transmitted directly from individual to individual.

How do Native people define traditional knowledge?

- It is practical common sense based on teachings and experiences passed on from generation to generation.
- It is knowing the country. It covers knowledge of the environment - snow, ice, weather, resources - and the relationships between things.
- It is holistic. It cannot be compartmentalized and cannot be separated from the people who hold it. It is rooted in the spiritual health, culture and language of the people. It is a way of life.
- Traditional knowledge is an authority system. It sets out the rules governing the use of resources - respect, an obligation to share. It is dynamic, cumulative and stable. It is truth.
- Traditional knowledge is a way of life -wisdom is using traditional knowledge in good ways. It is using the heart and the head together. It comes from the spirit in order to survive.
- It gives credibility to the people.

2. Scientific method

From Wikipedia, the free encyclopedia

The scientific method is a body of techniques for investigating phenomena, acquiring new knowledge, or correcting and integrating previous knowledge.[1]To be termed scientific, a method of inquiry must be based on empirical andmeasurable evidence subject to specific principles of reasoning. The *Oxford English Dictionary* defines the scientific method as "a method or procedure that has characterized natural science since the 17th century, consisting in systematic observation, measurement, and experiment, and the formulation, testing, and modification of hypotheses."

The chief characteristic which distinguishes the scientific method from other methods of acquiring knowledge is that scientists seek to let reality speak for itself, supporting a theory when a theory's predictions are confirmed and challenging a theory when its predictions prove false. Although procedures vary from one field of inquiry to another, identifiable features distinguish scientific inquiry from other methods of obtaining knowledge. Scientific researchers propose hypotheses as explanations of phenomena and design experimentalstudies to test these hypotheses via predictions which can be derived from them. These steps must be repeatable to guard against mistake or confusion in any particular experimenter. Theories that encompass wider domains of inquiry may bind many independently derived hypotheses together in a coherent, supportive structure. Theories, in turn, may help form new hypotheses or place groups of hypotheses into context.

Scientific inquiry is intended to be as objective as possible in order to minimize bias. Another basic expectation is the documentation, archivingand sharing of all data collected or produced and of the methodologies used so they may be available for careful scrutiny and attempts by other scientists to reproduce and verify them.

3. VIDEO: Vandana Shiva on Mechanists vs Scientific Knowledge" https://vimeo.com/103764529

When Vandana Shiva was reseracher her siminal book about women and ecology, *Staying Alive* (1989), her eyes were opened to the nature of science. The Neem tree she mentioned in this clip is indigneous to India, and has been used for centuries in Indian agriculture as a cure for ailing soils and plants. In 2000 The European Patent Office (EPO) revoked a patant on Neem that had been granted to the U.S. based on Grace Coproratio. Vanada's activistm was key to this victory. In its ruling the EPO agreed that the patent amounted to bio-piracy and the process for whaich the patent had been granted had in fact been used in India from time immemorial.

4. Watch "Science and the Scientific Method" https://vimeo.com/33295400

5. Complete attached table

Assignment 1: Ways of Knowing

	Indigenous knowledge	**Scientific knowledge**
How is the relationship between nature and culture perceived?		
What are the predicative abilities at various at local versus global scale?		
What types of data and explanations are generated?		
How is knowledge acquired?		
How is knowledge communicated and managed?		
Key Principles, concepts or descriptors		

Please use another page if necessary

Activity 2: Types of Data, Data Set 1

Indicators for weather pattern change

Low altitude regions

- Temperature is persistently rising during the last 5-6 years.
- Summer has advanced and winter has shrunk or at least remained the same.
- There is less cold during winter as compared to pat
- Cold used to last until *Falgun (Feb-Mar)*, now it is cold only in *Poush* (Dec-Jan) and *Magh* (Jan-Feb).
- Erratic and unpredictable rainfall patterns are more prevalent.
- Roads used to become invisible due to thick fog, now it is very rare.
- Thick black frost used to damage crops, now we don't see such frost.
- Heavy downpour is more frequent than before.
- We receive less rain and *jhari* (continuous rainfall) is more frequent but shorter in duration than before.
- It used to rain incessantly for a week, now it lasts for 4-5 days at maximum.
- Less water is collected in water ponds and water streams.
- During the spring, ponds used to be full of water, now not as abundant.
- People used to go fishing in ponds, now there's not enough water even for birds

High altitude regions

- Twenty years ago, temperature used to stay below 16^0C. Thus, a cheese factory was established. Now, the temperature has increased by about 3^0C.
- It used to be freezing cold some 5-10 years ago, now it is much less cold.
- It used to snow in Feb/Mar but now there is no snow during those months; January and February months are warmer (low altitude villages) than before.
- Several cattle used to die from heavy snow ~50 year ago; for the last 10-12 years the rate has declined.
- Lowest point of snowfall has shifted to high altitude belts (e.g. *Chitre* to *Lame dhura* village and *Sisne* to *Peng*).
- There is less snow (frequency and intensity), less fog, and more hailstones for the last 10 years; in some regions, there is even no snow and frost for last 3 years.
- In some areas, all trees and roads used to be covered with snow; people used to collect ice and heat it to get melted and drink.
- Snow used to remain for a week and we used to collect water from mountain tops as there was snow all around.
- Snow period is shrunk from 2.5 to 0 month.
- Frost used to last for 15 days, now we get it for much shorter period.
- We require less amount of firewood as the winter is becoming warmer.
- People were not able to take their children out of room due to cold, now not as cold as it used to be.
- We used to sit by fire for 4-5 hours during winter, now we don't need to sit by fire.
- It was very difficult to touch water with bare hand during the winter, now there is no problem in touching it.

Source: ***Chaudhary, Pashupati and Kamaljit S. Bawa. 2011. "Local perceptions of climate change validated by scientific evidence in the Himalayas". Biological Letters.*** 7 (5): 767–770. Data collected in focus group discussions in 10 villages. All available people were invited. During the discussions, participants were prompted to discuss issues related to climate change and its impacts in the locality, using a check-list containing open-ended questions.

Activity 2: Types of Data, Data Set 1, continued

Indicators for change in agriculture

Low altitude regions

- Maize ripens earlier by about 15 days and gets dried due to overheat.
- Cabbage and cauliflower used to ripen in 3 months, now they ripen in 2 months and a half.
- Broom grass, potato, chilly, and tomatoes mature and ripen earlier.
- Maize, wheat, cardamom, cabbage, cauliflower, tomato, carrot, zinger, onion, beet, etc. can grow well now; only local radish landrace was grown before due to extreme cold and heavy frost.
- Frost used to damage cardamom, now we can grow it without a problem.
- Mango has adapted well in our soil.
- Broom grass now grows in much higher altitude regions, so does *Schima wallichii*.
- Cardamom and marigold die due to wilting caused by over heat.
- Marigold gets dried and dies out due to heat.
- A new disease in marigold, maize and potato has been observed.
- *Furke* disease (decaying plants) is seen in cardamom.
- *Pudke* (small) bug is more prevalent than before.
- Yield reduction in ginger in low altitudes.
- *In Himali* rice we used to get about 50% grain-filling, now we get about 80%.
- Corn is less tasty due to early maturity.
- New unknown livestock diseases are seen.

High altitude regions

- *Jhyale* potato landrace still grows well in higher altitude, but not in lower altitudes.
- New pathogens have been observed in soil.
- Nodule formation in root and stunted growth in curd of cauliflower and cabbage.
- Weeding in maize is done in Ashar (June-July), used to do in Jestha (May-June).
- Milk production in livestock is reduced due

Source: ***Chaudhary, Pashupati and Kamaljit S. Bawa. 2011. "Local perceptions of climate change validated by scientific evidence in the Himalayas". Biological Letters.* 7 (5):** 767–770. Data collected in focus group discussions in 10 villages. All available people were invited. During the discussions, participants were prompted to discuss issues related to climate change and its impacts in the locality, using a check-list containing open-ended questions.

Activity 2: Types of Data, Data Set 1, continued

Indicators for shift in bio-physiology
Low altitude regions • Chrysanthemum used to flower during Dashain festival, now flowers little earlier. • Flowering in some orchids advanced as early as 2 months. • *Gagun (Saurauia nepalensis)*, a fodder tree, sprouts twice a year as summer is longer. **High altitude regions** • *Plum (Prunus cerasoides)* and *Macaranga spp*. trees get dried due to overheat, but they have started growing well in higher altitude regions. • New species of bees and wasps now travel occasionally or have moved to our locality from low altitude regions. • Mosquitoes have been observed for the last 4 years. • We now require net to protect us from mosquito biting. • A leech species common in terai (lowlands) region are seen. • A strange rodent species has been observed. • Rhododendron, *ainselu (Rubus ellipticus)*, peach, pear, and marigold flower earlier than before. • *Malata (Macaranga spp.),* Nepali alder (*Alnus nepalensis), chilaune (Schima wallichii)), kholme (Symplocos laurina), and kharane (Symplocos theirfolia) have been* growing better for the last 10 years in our location. • New species seen in the region: *Schima wallichii, Katush (Castanopsis spp.), Siris (Albizzia spp.), Macananga spp., and Nepali alder.* • *Nepali alder, a kukath* (poor quality wood), grows well now; before it could not tolerate cold weather and frost.

Source: ***Chaudhary, Pashupati and Kamaljit S. Bawa. 2011. "Local perceptions of climate change validated by scientific evidence in the Himalayas". Biological Letters.*** 7 (5): 767–770. Data collected in focus group discussions in 10 villages. All available people were invited. During the discussions, participants were prompted to discuss issues related to climate change and its impacts in the locality, using a check-list containing open-ended questions.

Activity 2: Types of Data, Data Set 2

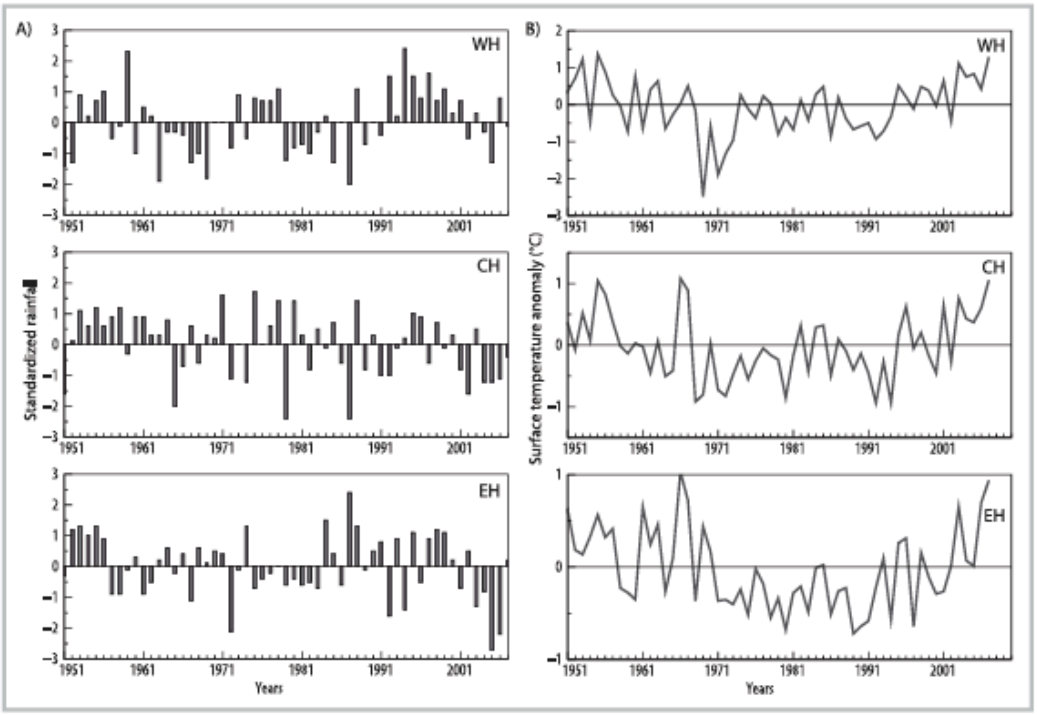
Box 2. Narratives and evidence from the Yakutsk region.	
"Lakes are sinking as the permafrost melts, which means many fishing lakes have been lost. People have to go further, which is hard as the price of fuel goes up. Reindeer herders select routes based on weather forecasts so mistakes have detrimental effects." *Source*: Vyacheslav Shadrin, Head of the Council of Yukagir Elders, 2005.	Mean monthly soil temperature data for 1930–1990 indicate that as temperatures have been rising, the active layer of permafrost has been deepening and the freezing depth has become more shallow. *Source*: Frauenfeld et al. 2004.

Box 3. Narratives and evidence from the Beaufort Sea area.	
Many Iñupiaq interviewees emphasized that the ice condition was out of the ordinary in both 2005 and 2006… An elderly captain stated that the 2006 spring season harvest in the North Slope Borough was the lowest in the past 35 years. *Source*: Sakakibara 2009. "Those poor whales out there in the ocean that we depend on. Are they going to come back to us? Are they going to really show up next year, like our ancestors always expected them for 20,000 years? We are heartily concerned." *Source*: Earl Kingik, Iñupiaq tribesman.	Record melting during 2005 allowed old, thick ice from the north to drift into the Beaufort Sea. Some of this ice from the increased melting was pushed by wind toward the shore in 2006. Though there was more ice in the Beaufort Sea at the end of July 2006 than there had been in previous years, the Arctic as a whole continued to melt at an ever-quickening pace. By June 2006, sea ice in the Arctic covered 1.2 million fewer square kilometers than the long-term average measured between 1979 and 2000. This put sea ice concentrations (the percentage of ice that covers a predefined area) at a record low for June, breaking the record set in June 2005, during which sea ice extent was down 0.8 million square kilometers from the average. *Source*: NASA Earth Observatory 2007.

Student Handouts_Activity 2_Data Set 2_Source: Alexander, Clarence, et al. 2011. "Linking Indigenous and Scientific Knowledge of Climate Change". BioScience 61(6): 477-484.

Activity 2: Types of Data, Data Set 3

Figure 2: (A) Interannual variability of standardized Jun through September rainfall and (B) anomalies of annual average temperature in centigrade 1951-2007 in WH: western Himalaya; EH: eastern Himalaya; CH: central Himalaya



Source: Kulkarni, Ashwini , Savita Patwardhan K. Krishna Kumar, Karamuri Ashok, and Raghavan Krishnan. 2013 "Projected Climate Change in the Hindu Kush–Himalayan Region By Using the High-resolution Regional Climate Model PRECIS". Mountain Research and Development, 33(2):142-151.

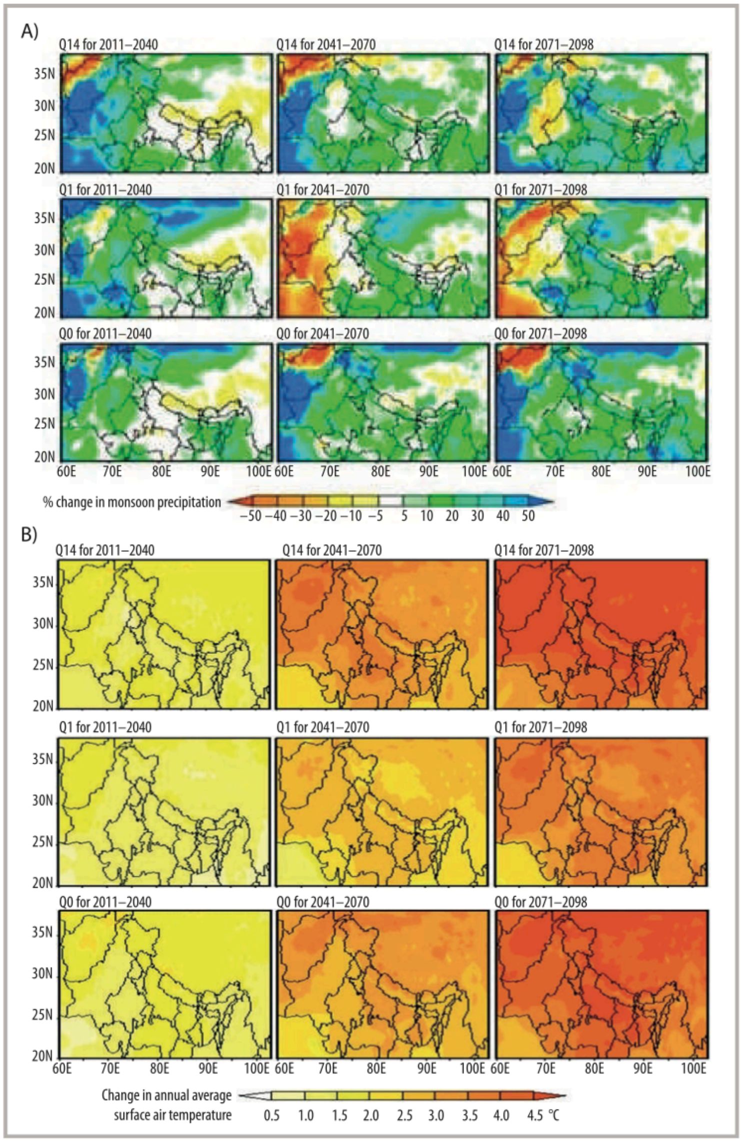


Figure 6 (A) Percentage change (compared 1961-1990 baseline) in monsoon precipitation; (b) change in average annual surface temperature in 3 QUMP experiment in 3 time periods

QUMP: Quantifying Uncertainty in Model Predictions project

Source: Kulkarni, Ashwini , Savita Patwardhan K. Krishna Kumar, Karamuri Ashok, and Raghavan Krishnan. 2013 "Projected Climate Change in the Hindu Kush–Himalayan Region By Using the High-resolution Regional Climate Model PRECIS". Mountain Research and Development, 33(2):142-151.

Activity 3a: Data Integration Questions

Activity 3: Prior to class read peer-reviewed article " 'We Like to Listen to Stories about Fish': Integrating Indigenous Ecological and Scientific Knowledge to Inform Environmental Flow Assessments". Answer the questions below in draft form in preparation for class discussion.

1. Look at the list of authors and their associations. What does this tell us about the project?
2. How would you characterize the partnership between indigenous people and scientific researches in this research project?
3. What mechanisms were used to form the partnership? In your opinion, is anything missing in how the partnership was formed?
4. How did the scientists and indigenous people collaborate to integrate their knowledge systems?
5. What were the major benefits of the integration for indigenous people?
6. What were the major benefits of the integration for the scientists?
7. What were the limitations of the integration?
8. What is science better equipped to show?
9. What is indigenous knowledge better equipped to show from the scientists' perspective?

Jackson, S. E., M. M. Douglas, M. J. Kennard, B. J. Pusey, J. Huddleston, B. Harney, L. Liddy, M. Liddy, R. Liddy, L. Sullivan, B. Huddleston, M. Banderson, A. McMah, and Q. Allsop. 2014. "We like to listen to stories about fish": integrating indigenous ecological and scientific knowledge to inform environmental flow assessments. *Ecology and Society* **19**(1): 43. http://dx.doi.org/10.5751/ES-05874-190143

Research

"We Like to Listen to Stories about Fish": Integrating Indigenous Ecological and Scientific Knowledge to Inform Environmental Flow Assessments

Sue E. Jackson [1,2], Michael M. Douglas [2,3], Mark J. Kennard [1,2], Brad J. Pusey [1,2,4], Jabal Huddleston [5], Bill Harney [6], Lenny Liddy [5], Mona Liddy [5], Robert Liddy [5], Lizzy Sullivan [5], Brenda Huddleston [5], Melissa Banderson [5], Andrew McMah [5] and Quentin Allsop [7]

ABSTRACT. Studies that apply indigenous ecological knowledge to contemporary resource management problems are increasing globally; however, few of these studies have contributed to environmental water management. We interviewed three indigenous landowning groups in a tropical Australian catchment subject to increasing water resource development pressure and trialed tools to integrate indigenous and scientific knowledge of the biology and ecology of freshwater fish to assess their water requirements. The differences, similarities, and complementarities between the knowledge of fish held by indigenous people and scientists are discussed in the context of the changing socioeconomic circumstances experienced by indigenous communities of north Australia. In addition to eliciting indigenous knowledge that confirmed field fish survey results, the approach generated knowledge that was new to both science and indigenous participants, respectively. Indigenous knowledge influenced (1) the conceptual models developed by scientists to understand the flow ecology and (2) the structure of risk assessment tools designed to understand the vulnerability of particular fish to low-flow scenarios.

Key Words: *Daly River; environmental flow; fish ecology; indigenous ecological knowledge; indigenous fish knowledge; integration*

INTRODUCTION

> *Brad (scientist): Bill, why are the white tail (strawman or black mask) in the same family?*
>
> *Bill (indigenous elder): Well they got a relation there, cousins, auntie and uncles.*
>
> *Brad: From the dreamtime?*
>
> *Bill: Yeah, from the dreamtime; they're all family.* (S. E. Jackson's field notes, Flora River, 15 July 2006)

Studies that apply indigenous ecological knowledge (IEK) to contemporary resource management problems are increasing in number globally (Silvano and Begossi 2002, Silvano et al. 2008, Stephenson and Moller 2009, Bohensky and Maru 2011). As a source of fine-grained, detailed information about local ecosystem patterns and process, indigenous knowledge can be valuable for natural resource assessments, especially in those areas where extant systems of customary resource management prevail and scientific knowledge (SK) is poor or nonexistent (Fabricius et al. 2006). We adopt Berke's (2004) definition of IEK as an accumulative body of knowledge, practice, and belief about the relationships that living things, including people, have with each other that is handed down through generations by cultural transmission.

The tacit, practical knowledge gained from centuries of daily resource use is often of most interest to ecologists and resource managers (Butler 2006). Esselman and Opperman (2010), for example, surveyed the fish biology literature and concluded that indigenous fishermen have the ability to recognize taxa, behavioral traits, and spatiotemporal changes in fish assemblage composition across seasons and, in addition, can accurately attribute causation to complex limnological occurrences. In understudied regions, some of this tacit knowledge is likely to be new to science (e.g., Morgan et al. 2002, Foale 2006, Silvano et al. 2008).

The ability to integrate IEK with SK remains a challenge (Bohensky and Maru 2011, Hill et al. 2012), not least because of the very different cognitive contexts in which indigenous people and researchers make their observations. In addition to stimulating considerable academic debate (Agrawal 1995, Wilson 2003, Butler 2006), the methodological and epistemological differences based on worldviews and approaches to investigating reality have resulted in many integration projects falling well short of both indigenous and nonindigenous expectations (Nadasdy 2005). Differences between knowledge systems do not necessarily impede integration efforts, however (Bohensky and Maru 2011). Hviding (2006:71) sees great value in partnerships that seek an understanding of similarities, differences, and complementarities between knowledge systems, arguing that "where there is contrasting knowledge, there is also potential for dialogue and convergence."

We take up Hviding's challenge to develop research partnerships across cultures by examining the similarities and differences in IEK and SK relating to the ecology of fish in a tropical catchment and consider the value of combining these knowledge sources to improve water planning and management. Fish are of significant cultural and economic value to the indigenous household economy in remote regions of northern Australia (Altman 1987, Jackson et al. 2012, Stoeckl et al. 2013), and subsistence strategies rely on ecological knowledge of seasonal fish distribution and movement (Raymond et al. 1999, Liddy et al. 2006, Woodward et al. 2012). Fish research, or "listening to stories and talking about

[1]Australian Rivers Institute Griffith University, [2]TRaCK, [3]NERP Research Hub, Charles Darwin University, [4]Centre of Excellence in Natural Resource Management, University of Western Australia, [5]Wagiman Traditional Owner, [6]Wardaman Association, [7]NT Fisheries Research, Northern Territory Department of Resources

fish" in the words of indigenous study participants, is an activity for which there is undoubtedly an "everyday enthusiasm" (Hviding 2006:82).

The management context for this inquiry is the determination of environmental water requirements of fish. Increasing development pressures in northern Australia have added a sense of urgency to synthesizing existing fish knowledge (Douglas et al. 2011). The ecological impacts of anthropogenic changes in river flows are currently poorly understood by the scientific community, and data available for developing environmental flow recommendations for fish are scarce or completely lacking for most tropical Australian rivers (Pusey et al. 2011). Regions like northern Australia may nonetheless have a well-developed knowledge base resident in the indigenous population (Finn and Jackson 2011). Indigenous knowledge, which can be geographically and temporally more extensive than SK (Fraser et al. 2006), may be of value for its relative empirical strength.

We therefore trialled an integrated approach to environmental flow assessment (Chan et al. 2012) that drew on indigenous knowledge as a complementary source of knowledge. Our aims were to (1) compare and contrast the scientific and indigenous knowledge of fish and flow ecology; (2) consider the benefits of integrating these knowledge sources for environmental flow assessment; and (3) outline the ethical, cultural, and logistical challenges of designing and conducting cross-cultural ecological research.

METHODS

Study area

Ecohydrological and socioeconomic characteristics

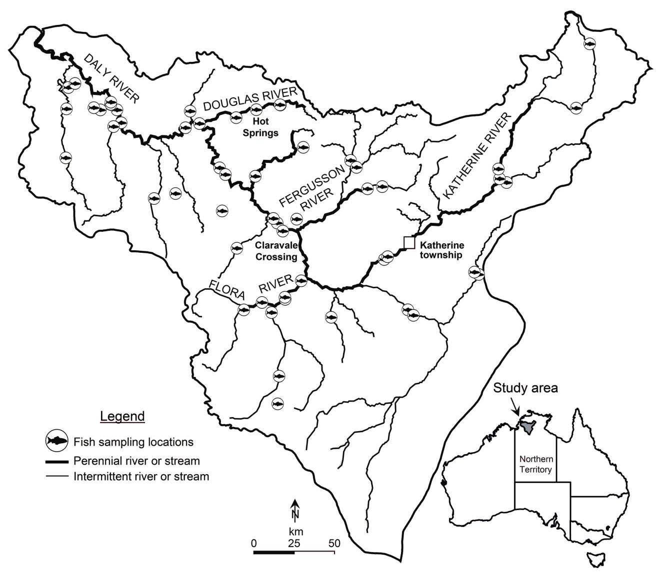
The Daly River catchment lies in the Australian northwestern wet/dry tropics agroecological region (Fig. 1) where the natural vegetation cover ranges from eucalypt forest to low open grassland. The catchment is sparsely populated (10,000 people; Carson et al. 2009). At least 10 indigenous language groups comprise approximately a quarter of the total population and own approximately 27% of the land (Jackson 2006). The river and its catchment are in relatively good environmental condition compared to other major rivers in Australia (Chan et al. 2012). Cattle grazing is the dominant land use alongside conservation, although dryland and irrigated cropping are of increasing importance in the middle reaches of the Daly River and its major upstream tributary, the Katherine River. Small areas of the catchment are devoted to more intensive land uses such as urbanization, pasture, and agriculture.

Water resource management

The Daly River has the fourth largest discharge of Australia's tropical rivers (CSIRO 2009), and its aquifers provide relatively reliable year-round flows. Reliable groundwater reserves and relatively good soils mean that of all the Northern Territory's (NT) regions it is most likely to be further developed for agriculture. Existing agricultural and mining industries already place pressure on the catchment's water resources (Begg et al. 2001).

Previous environmental flow studies examined the requirements of aquatic and riparian plants, algae, and the pig-nosed turtle (*Carettochelys insculpta*; Erskine et al. 2003). However, the river also supports more than 50 species of freshwater and estuarine fish and elasmobranchs, including some endangered and vulnerable species (Pusey et al. 2011), but fundamental knowledge of the ecology of these species, such as their distribution, habitat preferences, and breeding phenology, is lacking, and consequently, little is known about their environmental water requirements.

Fig. 1. The Daly River catchment, northern Australia, showing the fish sampling sites and locations mentioned in the text.



Indigenous land and water management

Changes in land use and settlement patterns caused by colonial and postcolonial policies have consolidated indigenous populations across north Australia, significantly disrupting subsistence strategies with consequences for health, well-being, and economic and cultural life (Keen 2003). Loss of ecological knowledge is a further consequence of the massive disruption that indigenous societies have experienced over the past 150 years.

Indigenous collective formations with traditional connections to land and water within the Daly River catchment include the Jawoyn, Wardaman, and Wagiman language groups, although there are others (see Jackson 2006). Social solidarity amongst indigenous groups is supported by common descent from shared ancestors, a sense of common traditions, and a mostly shared lifestyle nearby or on customary estates (Jackson 2006, Jackson et al. 2011). Each language-owning group has asserted its customary rights to identifiable territory under Commonwealth land rights legislation, i.e., Aboriginal Land Rights (Northern Territory Act) 1976, and, from the early 1980s, was awarded grants of freehold title to significant portions of land. Having demonstrated to the satisfaction of the Australian courts that they each share a body of knowledge about the area, claimants must also show that they are entitled to forage over the claim area, as evident in their extensive knowledge of edible food including fish, bush medicines, and natural resources.

Concern about the rapidly attenuating local knowledge base has motivated these groups to partner with scientists and undertake activities to conserve their knowledge. For instance, Wagiman (Liddy et al. 2006), Jawoyn (Wiynjorrotj et al. 2005), and Wardaman (Raymond et al. 1999) elders have published their detailed, extensive plant and animal knowledge in collaboration with linguists and scientists.

Study design

The project was primarily focused on assembling information on the ecological requirements of freshwater fish to assist decision makers to assess the risk of flow alteration scenarios for the Daly River (see Pusey and Kennard 2009, Chan et al. 2012, Stoeckl et al. 2013). We applied a multistep process that included hydrological analysis and modeling, the collection of scientific and indigenous knowledge during field trips, literature reviews, expert consultation, and environmental flow workshops for scientists, water managers, and community members.

Scientific knowledge collection

We distinguished three sources of SK about the freshwater fish: (1) new data collected by the project team during field sampling, (2) information available from past studies in the Daly River, and (3) information from other catchments in tropical northern Australia. New data collected by the project team during field sampling involved quantitative sampling of fish communities at multiple sites throughout the catchment during the early and late dry season from 2006 (see Stewart-Koster et al. 2011 and Chan et al. 2012 for a detailed description of sampling methods). This yielded information on the distribution, abundance, habitat use, diet, and influence of flow on fish communities (reported in Davis et al. 2010, 2011, 2012*a*, *b*, *c*, Cook et al. 2011, Chan et al. 2012, Hermoso and Kennard 2012, Linke et al. 2012, Pettit et al. 2013). Information available from past studies in the Daly River included distribution records, i.e., Museum and Art Gallery of the Northern Territory; small-scale, one-off surveys of fish distribution and abundance (Midgley 1980, Wilson and Brooks 2004); and a study of seasonal fish movements in a single tributary (D. Warfe, Charles Darwin University, *unpublished data*). Information collected from other northern Australian catchments on the habitat use, diet, and life history of some species was also sourced from Merrick and Schmida (1984), Larson and Martin (1990), Bishop et al. (2001), and Pusey et al. (2004).

Research partnerships with indigenous landowners

The project secured the consent and involvement of the three indigenous language groups, i.e., Wagiman, Wardaman, and Jawoyn, from the middle and upper sections of the Daly River during preliminary meetings in 2005. Indigenous groups were invited to join as study partners in recognition of their twin roles as custodians with local knowledge of their customary estates and as statutory landowners. Both roles generate rights and responsibilities with respect to natural resource management. Indigenous groups had a number of motivations for participating. First, a formal partnership would provide indigenous oversight of the research activity, ensuring that indigenous protocols were followed, and, in doing so, safeguard the well-being of research parties visiting indigenous lands and waters. Second, a research partnership could provide opportunities such as field-sampling activities to build the capacity of landowning groups to make well-informed decisions about water use and wider catchment management practices. Third, it was hoped that a partnership would stem the rapid attenuation of indigenous knowledge in the region, primarily by restoring connections to customary estates. The project's heavy emphasis on field-based survey techniques would generate opportunities to visit the country; carry out management activities, such as activating dreaming and ancestral spirits; and exchange and transfer knowledge within indigenous groups, particularly, it was hoped, across generations (Smyth 2012).

The terms of the research partnership were negotiated under research agreements that established protocols for research and communication activities, promoted the sharing of benefits, and ensured protection of indigenous intellectual property. Approval for our research was granted by the human ethics committee at Charles Darwin University. From 2005, indigenous participants frequently contributed their time and knowledge to fish-sampling activities at a number of sites. Two Wagiman representatives, i.e., Mona Liddy and Lizzie Sullivan, and one Wardaman representative, i.e., Bill Harney, were members of the project's Steering Committee.

At a Wagiman Association meeting in 2011, researchers proposed the development of a scientific paper on the results of the project's indigenous knowledge component. A small writing group was then formed from amongst the Wagiman to progress the paper that was written iteratively over an extended period of face-to-face meetings. The authorship list is composed of a wider group of indigenous experts who contributed their knowledge.

Indigenous ecological knowledge collection

We used both semistructured group interviews and unstructured one-to-one interviews with indigenous participants to record their knowledge of freshwater fishes. The former was the primary method of data collection for ecological knowledge of fish species, and other information relating to language name and customary use was also recorded. Interviews were conducted at fish-sampling sites at the time of sampling to assist in identification and discussion. Fish collected during sampling were retained alive in aquaria for the duration of interviews to provide reference and were later returned alive to the point of capture.

A common series of 12 questions was put to 2 language groups at Flora River, where 7 Wardaman participated; Claravale Crossing, where 18 Wagiman participated; and Tjuwaliyn Hot Springs, where 7 Wagiman participated (see Fig. 1). At the request of the participants, interviews were conducted with each group rather than individuals, although 3 interviews were held with 2 particularly knowledgeable elders and video recorded. Questions covered a range of topics relating to aspects of fish ecology that could be impacted by altered dry-season flows, i.e., distribution and abundance, habitat preference, trophic ecology, and reproduction (see Table 1). To avoid confusion over species identifications, the systematic surveys were done only for the 15 fish species that were collected during the field research with indigenous participants and for 3 elasmobranchs that were large and easily identifiable. Field notes were taken to supplement points raised during completion of the survey sheet and to record knowledge of fish species not caught on the day of the interview.

A number of steps were taken to ensure that the information recorded was valid and accurate. First, indigenous experts were

Table 1. Similarities and differences between indigenous ecological knowledge (IEK) and scientific knowledge (SK) related to environmental flow assessments for 15 fish species from the Daly River, Northern Territory. Categories are: Congruent (=) when IEK and documented SK from either the Daly or another river system were consistent or when IEK added new knowledge that complemented or extended existing SK for the Daly River; Incongruent (≠) when IEK and documented SK are inconsistent; No knowledge (0) when there was documented SK but no IEK. The two cases for which there was no SK or IEK are shown in bold type.

Interview question	Data for environmental flow assessment	Fish species[†]														
		NG	BG	MA	GO	BB	ST	SP	T	NC	HT	SC	GI	RC	SA	FL
What time of year do you see them?	Seasonal variation in abundance	0	=	0	0	=	0	=	0	0	=	=	0	0	=	0
Do you see more in big floods or dry years?	Interannual variation in abundance	0	=	=	=	=	=	=	=	=	=	0	0	=	=	=
What eats it?	Predation	0	=	=	=	0	**0**	=	=	=	0	=	0	=	**0**	=
Where in the river system is it caught/found?	Distribution in river system	0	0	=	≠	=	=	=	0	=	=	=	0	=	=	=
What sorts of places are young ones caught/found?	Juvenile habitat use	=	=	=	≠	=	=	≠	0	0	=	0	=	=	0	=
What sorts of places are adults caught/found?	Adult habitat use	=	=	=	≠	=	=	≠	=	=	=	=	=	=	≠	=
Does it move to other parts of river?	Movement patterns	0	=	=	=	=	=	=	=	=	=	=	0	=	=	=
Where does it breed?	Spawning habitat	0	0	0	0	≠	≠	=	≠	=	=	=	0	0	0	=
Where does it breed?	Spawning substrate	0	0	0	0	≠	≠	0	0	0	0	=	0	0	0	0
When does it breed?	Spawning season	0	0	0	≠	=	0	=	0	≠	0	=	0	=	0	=
What does it eat?	Feeding requirement	0	=	=	=	=	=	=	=	=	=	=	0	≠	=	=
Does fish health change, e.g., fat during wet season, more disease during late dry?	Fish condition	0	0	0	0	=	=	=	0	=	0	=	0	=	=	=

[†]Species codes: NG = Northwest glassfish, *Ambassis sp. (cf muelleri)*; BG = Barred grunter, *Amniataba percoides*; MA = Mouth almighty, *Glossamia aprion*; GO = Golden goby, *Glossogobius aureus*; BB = Black bream, *Hephaestus fuliginosus*; ST = Freshwater stingray, *Hymantura dalyensis*; SP = Spangled perch, *Leiopotherapon unicolor*; T = Tarpon, *Megalops cyprinoides*; NC = Narrow-fronted catfish, *Neosilurus ater*; HT = Hyrtl's catfish, *Neosilurus hyrtlii*; SC = Sleepy cod, *Oxyeleotris lineolatus*; GU = Giant gudgeon, *Oxyeleotris selheimi*; RC = Rendahl's catfish, *Porochilus rendahli*; SA = Freshwater sawfish, *Pristis pristis*; FL = Freshwater longtom, *Strongylura krefftii*

initially nominated by the regional indigenous organization responsible for land management on indigenous lands. Following extensive community consultation over two years, the research team was confident that the most knowledgeable people were involved through a process of peer selection endorsed by Huntington (2000); some had demonstrated their knowledge in legal proceedings and sacred site registration processes. Second, indigenous language names were sought for those fish caught during interviews. Attribution of customary names to individual species confirmed that pertinent knowledge was directly relatable to that species. Third, on the occasion that a question yielded an uncertain response, the issue was revisited and clarified on a subsequent sampling trip or at a community meeting through a process of group review (Huntington 2000). A linguist specializing in languages from this region was contacted for confirmation of fish names.

Comparison of scientific knowledge and indigenous ecological knowledge

The SK and IEK for each question were compared and classified according to three categories: "congruent," where IEK and documented SK from either the Daly or another river system were consistent or where IEK added new knowledge that complemented or extended existing SK for the Daly River; "incongruent," where IEK and documented SK were inconsistent; and "no knowledge," where there was no IEK.

RESULTS

Sources of scientific knowledge of freshwater fish in the Daly River

Fish sampling undertaken as part of this project provided on average 59% of the SK for the 15 fish species, with relatively little information collected for freshwater sawfish (*Pristis pristis*) and freshwater stingray (*Hymantura dalyensis*), which were rarely sampled (Fig. 2a). Information from other river systems provided 31% of SK, whereas previous studies in the Daly River provided only 5% of SK and covered only 9 species (Fig. 2a). There was no SK available for 5% of responses, and this was from just 2 questions, i.e., predation (50% of species) and fish condition (< 20% of species; Fig. 2b).

The fish sampling conducted for this project provided the majority of the SK for 8 of the 12 questions related to environmental flow assessments (Fig. 2b), including 75-100% of SK on seasonal and interannual variation in fish abundance, distribution, habitat use, fish condition, and spawning season (Fig. 2b). Data collected from other river systems contributed 50-95% of the information for 4 questions related to spawning habitat, movement biology, and feeding requirements, and less than 30% for questions on seasonal patterns of abundance and spawning (Fig. 2b). Previous scientific research in the Daly only contributed to 2 questions, accounting for about 30% of the information on movement and less than 15% for adult habitat use. There was no SK on predation for half of the species or for fish condition for 15% of species.

Fig. 2. Summary of scientific knowledge sources by (a) fish species and (b) topic of interview questions relevant to environmental flow assessments of fish in the Daly River. Scientific knowledge sources were categorized as no information, published literature from other catchments or closely related species, existing data collected for the Daly River, and new data collected during this study. Information is summarized for (a) each fish species (% of responses to each of the 12 interview topics) and (b) each interview topic (% of responses for each of the 15 species).

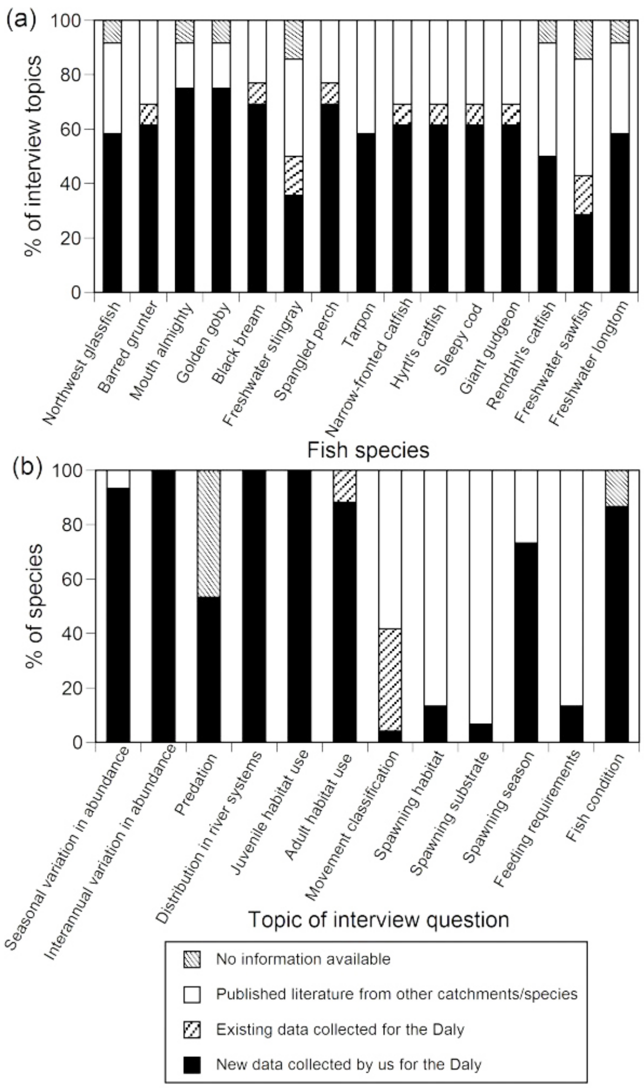
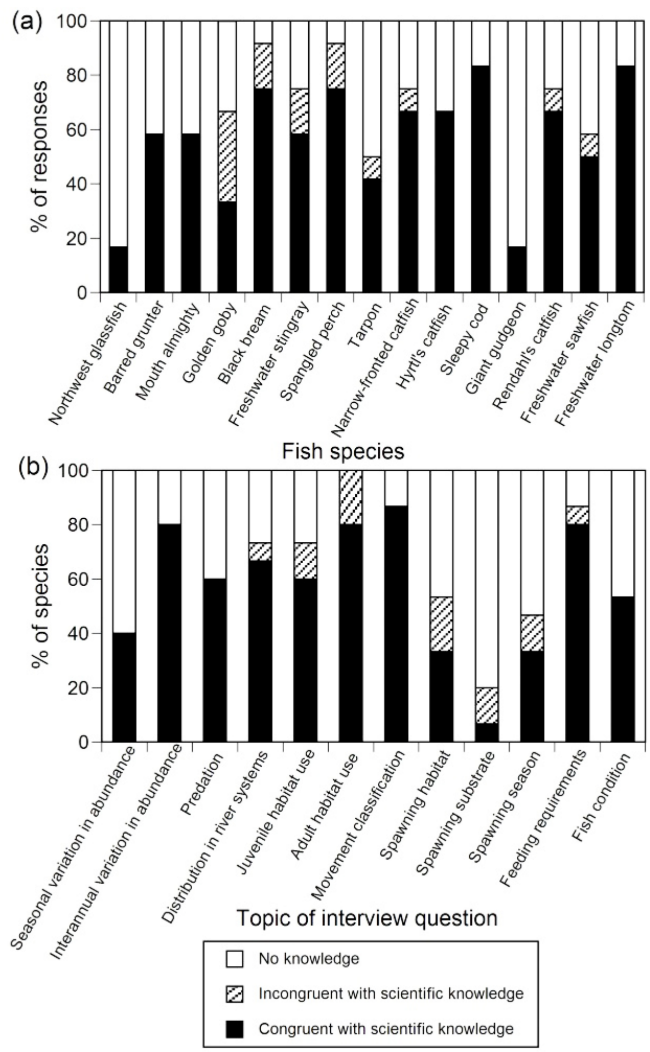


Fig. 3. Summary of indigenous ecological knowledge by (a) fish species and (b) topic of interview questions relevant to environmental flow assessments of fish in the Daly River. Categories are as follows: congruent where indigenous ecological knowledge and documented scientific knowledge from either the Daly or another river system were consistent or where indigenous ecological knowledge added new knowledge that complemented or extended existing scientific knowledge for the Daly River; incongruent where indigenous ecological knowledge and documented scientific knowledge were inconsistent; and no knowledge where there was no indigenous ecological knowledge. Information is summarized for (a) each fish species (% of responses to each of the 12 interview topics) and (b) each interview topic (% of responses for each species).



Indigenous ecological knowledge of freshwater fish in the Daly River

Systematic interviews with indigenous participants yielded 180 responses to the 12 questions, i.e., 15 species by 12 questions. Respondents had most knowledge of the fish species that were routinely caught and eaten or were easily observed, such as black bream (*Hephaestus fuliginosus*), barred grunter (Amniataba percoides), and sleepy cod (*Oxyeleotris lineolatus*; Table 1, Fig. 3a). No information was reported for about one-third (36%) of the questions, occurring most frequently in response to questions about spawning, i.e., substrate, season, and habitat; seasonal variation in abundance; and fish condition (Table 1, Fig. 3b). IEK was congruent or extended/complemented existing SK for more than half the responses (57%; Table 1, Fig. 3b). This included knowledge of feeding requirements for 12 of the 15 species and of the predators for more than half of the species, particularly the smaller bodied fish, and habitat use for 9 of the 15 species.

Indigenous respondents frequently identified the role of predation as an important influence on the ecology of fish in the Daly River. For example, many species such as the plotosid catfishes, gudgeons (Eleotridae), tarpon (*Megalops cyprinoides*), and grunters (Terapontidae) were reported as being consumed by barramundi (*Lates calcarifer*); cannibalism was also reported to occur frequently. Predation was suggested to be important in determining the small-scale habitat use of some species, i.e., use of undercut banks as a refuge from predation. For example, the mouth almighty (*Glossamia aprion*), i.e., *Gamarl* in Wagiman language, was said to always be associated with cover, otherwise "He'd be dead ... barra would eat 'im" (S. E. Jackson's field notes, Claravale Crossing, 27 August 2006). Similarly, the cryptic coloration of the golden goby (*Glossogobius aureus*) was said to be important in reducing predation.

The high frequency of congruent responses likely represents a shared understanding by ecologists and indigenous fishers of what habitats fish are most likely to occur in and what they eat, the most important information for capturing fish. The case of black bream, which is a highly popular fish to eat, further illustrates this point (Jackson et al. 2012). Black bream was found to be the species ranked highest in terms of confirmed knowledge. The biology of this species is relatively well understood by science and favored as a food by indigenous participants over all others. It is also probable that the congruence of knowledge in these areas reflects the fact that some aspects of the biology of these species varies little over their geographic ranges (Pusey et al. 2004).

IEK that extended/complemented SK was most frequently reported for seasonal and interannual variation in abundance (13 species), fish condition (6 species), and movement pattern (7 species). Movement by fishes throughout the year was also heavily emphasized in conversations, and floods were seen as important in stimulating migration upstream into tributaries or into floodplain wetlands. Changes in fish condition at different times of the year were also stressed. Black bream were said to be fattest during the wet season (see also Pusey et al. 2004 for black bream in Magela Creek). Plotosid catfishes (*Libiyan*/*Barrhbarrin*) were fattest at the end of the wet season, whereas sawfish (*Jalamariny*) were fattest in the dry season. Sleepy cod (*Gubulu*) became sick with external sores during the dry season, especially in billabongs. IEK also provided additional information on the distribution and habitat use of several rare species, including freshwater stingray and freshwater sawfish, as well as habitat use for common species like the sleepy cod and Hyrtl's catfish (*Neosilurus hyrtlii*; Table 1).

IEK and SK were incongruent for only 8% of responses, and these instances were mostly restricted to questions about habitat use and spawning requirements (Table 1, Fig. 3b). Of the 15 fish species that were the subject of interviews, only 2 species, black bream and golden goby, were caught in the presence of both Wagiman groups. The responses to questions about these 2 species revealed differences between groups in their level of knowledge of the goby and some inconsistencies in knowledge of spawning season, distribution, and fish condition for black bream.

In addition to the structured surveys, discussions with Wagiman and Wardaman participants about the 28 fish species that researchers collected on field trips in their absence yielded new knowledge on the large-scale distribution in the river system, for example, upper, middle, or lower reaches, for 5 species, i.e., bull shark (*Carcharhinus leucas*), fork-tailed catfish (*Neoarius graeffei*), snub-nosed garfish (*Arrhamphus sclerolepis*), black-banded rainbowfish (*Melanotaenia nigrans*), and false-spined catfish (*Neosilurus pseudospinosus*), and congruent information for 5 other species, i.e., fly-specked hardyhead (*Craterocephalus stercusmuscarum*), Ord River mullet (*Liza ordensis*), northern trout gudgeon (*Mogurnda mogurnda*), primitive archerfish (*Toxotes lorentzi*), and seven-spot archerfish (*Toxotes chatareus*). It also yielded congruent information on the spawning preferences of the lesser salmon catfish (*Neoarius leptaspis*).

DISCUSSION

Characteristics and limitations of the knowledge sources for environmental flow assessment of fish in the Daly River

The different knowledge sources used in this project have different strengths and limitations when applied to environmental flow assessments (Table 2). Before this research, there was little SK to support environmental flow assessments for fish in the Daly River. Although there was relevant SK from other river systems, most of these systems have profoundly different flow regimes from that of the Daly River, so the valid transfer of this information is uncertain. The two-year program of fish sampling was specifically designed to gather scientific data to support environmental flow assessments. It was undertaken throughout the catchment, but some sites were only visited once, and all sampling was done during the dry season. This provided the majority of SK relating to topics such as habitat use, distribution, and changes in abundance but provided no information on topics such as feeding requirements or where fish spawn; SK on these topics came primarily from other river systems.

IEK in the Daly has accrued over generations for the purpose of hunting fish for food, and it too has limitations. Some inconspicuous species were less familiar to indigenous participants, and this provided an opportunity to produce "new" knowledge and learn from research collaborations, as the case of the freshwater sole (*Leptachirus triramus*) shows. This species is small and exceedingly cryptic and was not known to Wagiman participants prior to the electrofishing fieldwork when it was located buried in the sandy river bed. Its "discovery" highlights the dynamic quality of local environmental knowledge, which is undergoing constant modification as circumstances change.

The small scale of indigenous territories or customary estates can also limit IEK (Rose 1996), and this may be particularly evident with respect to migratory species (Kennett et al. 2004). For example, in an unstructured interview, a very knowledgeable Wardaman elder reported that barramundi spawn in the upper reaches of the catchment. It is most likely that this inaccurate observation is explained by the fact that Wardaman country is very distant from the river mouth where Western science has shown conclusively that spawning of the migratory barramundi occurs (Pusey et al. 2004). Differences in observational opportunities of this kind led to Felt's (1994) description of indigenous knowledge as partial, instrumental knowledge, which,

Table 2. Characteristics of knowledge sources used in the project and an assessment of their suitability and potential limitations for environmental flow assessment of fish in the Daly River.

Source of knowledge	Characteristics of data collection	Potential limitations for environmental flow assessments in the Daly River
Indigenous knowledge from Wagiman and Wardaman Traditional Owners	Collected over generations (> 1000 years) throughout the year, but more frequently during dry season Collected from multiple sites within clan boundary, range of stream orders, range of habitats. Covering < 100 km of river length; Very high level of taxonomic certainty	Collected from the Daly River for very different purposes, i.e., hunting, but some information directly relevant; Biased toward species caught for food or bait and easily observed; recent collections biased to dry season; limited knowledge of some cryptic species; limited information for some highly migratory species for which elements of life history occur outside of language group boundaries
Field surveys conducted in the Daly River for this project	Collected over two years early and late in the dry season Multiple sites covering most of the river system and a range of habitats, covering #62; 100 km of river length High level of taxonomic certainty	Collected from the Daly River specifically to inform environmental flow assessments. Biased toward species more catchable by electrofishing; no wet season information; limited interannual data; limited data on spawning habitats, feeding preferences, or movement biology
Past field surveys conducted in the Daly River	Collected over less than two years mostly during the dry season but some wet season sampling, Collected from a limited number of sites across river system, range of habitats but most collected from < 100 km of river length High level of taxonomic certainty	Collected from the Daly River for a range of purposes, e.g., distribution mapping, fish movement, but some information directly relevant for environmental flow assessments. Biases depending on sampling method, mostly gill, seine, and fyke netting; limited number of sampling locations and limited interannual data.
Research from other river systems in northern Australia	Collected for up to five years during the wet and dry season, but mostly during the dry season Collected from multiple sites across river system, covering a range of habitats over > 100 km of river length. High level of taxonomic certainty	Collected for a range of purposes, e.g., basic ecological and life history studies, but some information directly relevant to knowledge needs for environmental flow assessments. Sampling biases depending on method; transferability of information uncertain as most collected in rivers with profoundly different flow regimes to the Daly River

in Newfoundland, resulted in indigenous fishers being less able than scientists to detect significant declines in salmon stock size from overfishing. Although it is necessary to be aware of the limitations of these different knowledge sources, there is a growing body of literature focusing on the complementary aspects of IEK and SK and the potential benefits of integration (Silvano et al. 2008, Stephenson and Moller 2009, Hill et al. 2012).

Benefits of integrating indigenous and scientific knowledge for environmental flow assessment of fish in the Daly River

We recognized four broad types of benefits for environmental flow assessments that came from integration of the SK and IEK (Table 3). First, where SK from the Daly was congruent with IEK, e.g., distribution, habitat use, and predation, integration provided a greater level of confidence in the SK, which was based on only two years of sampling during the dry season. This was apparent for fish distributions within the river system, which is particularly important for determining locally based environmental flow targets. Although a subset of sites was sampled on six occasions, most sites were sampled only once (see Stewart-Koster et al. 2011, Chan et al. 2012). In contrast, indigenous participants were able to draw on a much longer period of observation made over a broader range of seasonal conditions, resulting in extensions of the upstream range of estuarine species such as the occurrence of the bull shark to King River and the spotted scat (*Scatophagus argus*) to Bradshaw Creek. IEK from Wardaman participants confirmed that the snub-nosed garfish was often sighted at Flora River, representing another upstream range extension, even though it was only collected by researchers on one occasion. IEK also supported the scientific observations on habitat use. For example, results from only two years of sampling could be confirmed by Wagiman observations that the giant gudgeon (*Oxyeleotris selheimi*) commonly occurred in billabong habitats.

Second, where there was little SK from the Daly but a high level of congruence between IEK and SK from other river systems, for example, movement classification and feeding requirements, integration provided a greater level of confidence in extrapolating this SK to the Daly River. For example, indigenous participants confirmed that an observation from the Alligator Rivers (Bishop et al. 2001), i.e., that tarpon (*Lolorriying*) were often found at the junction of creeks waiting to feed on migrating fish, also applied

Table 3. Table 3. Assessment of the contribution of indigenous ecological knowledge (IEK) and scientific knowledge (SK) and the potential benefits of their integration for environmental flow management of fish in the Daly River. Assessments are based on the data from Figures 3a,b and 4a,b. IEK was assessed against existing SK available at the time of the interviews (Figure 2a,b).

Topic	Contribution of indigenous ecological knowledge (IEK)	Contribution of scientific knowledge (SK)	Key benefits of integration of knowledge sources for environmental flow assessments
Seasonal variation in abundance	No IEK for > 45% of species; IEK and SK congruent/complementary for 40% of species; No incongruent knowledge	Sampling for this project provided the SK for > 75% of species;	High level of local SK but conclusions limited because sites only sampled during the dry season. For the species for which there was IEK it provided validation of the short-term SK and/or additional information on wet season patterns. The lack of incongruence between SK and IEK provided greater confidence in both knowledge sources.
Interannual variation in abundance	No IEK for < 30% of species; IEK and SK congruent/complementary for > 75% of species; No incongruent knowledge	Sampling for this project provided the SK for > 75% of species	High level of local SK but conclusions limited because sites only sampled over two years. IEK confirmed the short-term patterns from the SK and provided complementary information for more than half of the species. The lack of incongruence between SK and IEK provided greater confidence in both knowledge sources.
Predation	No IEK for > 40% of species; IEK and SK congruent/complementary for > 50% of species; No incongruent knowledge	Sampling for this project provided the SK for 50% of species; no knowledge for 50% of species.	Moderate level of information from both knowledge sources highlighted the need for more research on many species. IEK provided validation of the use of the short term SK for about half the species. IK from surveys and unstructured interviews highlighted the important role of predation in the Daly River and this strongly influenced the structure of risk assessment models arising from this project (see Chan et al. 2012). The lack of incongruence between SK and IEK provided greater confidence in both knowledge sources.
Distribution in river systems	No IEK for < 30% of species; IEK and SK congruent/complementary for > 60% of species; Incongruent knowledge for < 10% of species	Sampling for this project provided SK for > 75% of species	High level of local SK but based on limited sampling of each site. IEK provided validation of the SK from short-term study confirming the regular occurrence of species from sites only sampled once during this study and provided additional information that extended the range of several species. Some incongruence in knowledge highlighted the need for more research for some species, particularly migratory species.
Juvenile habitat use	No IEK for < 30% of species; IEK and SK congruent/complementary for > 60% of species; Incongruent knowledge for < 20% of species	Sampling for this project provided the SK for > 75% of species	High level of local SK but based on limited sampling of each site. IEK provided validation of the use of the short-term SK for the majority of species and additional information for a few species. Some incongruence in knowledge highlighted the need for more research on the habitat use for some species.
Adult habitat use	IEK and SK congruent/ complementary for > 75% of species; Incongruent knowledge for < 20% of species	Sampling for this project provided the SK for > 75% of species	High level of local SK but based on limited sampling of each site. IEK provided validation of the use of the short-term SK for the majority of species and additional information for a few species. Some incongruence in knowledge highlighted the need for more research on the habitat use for some species.
Movement classification	No IEK for < 30% of species; EK and SK congruent/complementary for > 75% of species; No incongruent knowledge	Sampling from other river systems provided the SK for > 60% of species	Moderate level of local SK but based on limited sampling from several studies and mostly from the dry season. IEK validated the extrapolation of SK from other studies in the Daly River and from other river systems and provided additional information for several species. The lack of incongruence between SK and IEK provided greater confidence in the extrapolation of SK from other river systems.
Spawning habitat	No IEK for > 40% of species; IEK and SK congruent/complementary for < 40% of species; Incongruent knowledge for < 20% of species	Sampling from other river systems provided the SK for > 85% of species	The very low level of local SK and the moderate level of IEK highlighted the need for more research on spawning habitat in the Daly River for most species. Some incongruence in knowledge highlighted the need for caution in extrapolating SK from other river systems to the Daly River.
Spawning substrate	No IEK for > 75% of species; IEK and SK congruent/complementary for < 40% of species; Incongruent knowledge for < 20% of species	Sampling from other river systems provided the SK for > 85% of species	The very low level of local SK and IEK highlighted the need for more research on spawning substrate in the Daly River for most species. The relatively high level of incongruence in knowledge highlighted the need for great caution in extrapolating SK from other river systems to the Daly River.
Spawning season	No IEK for > 40% of species; EK and SK congruent/complementary for < 5% of species; Incongruent knowledge for < 20% of species	Sampling for this project provided the SK for > 75% of species	High level of local SK but based only on dry season sampling. The moderate level of IEK and some incongruence in knowledge highlighted the need for more research on the spawning season for many species in the Daly River an the need for caution in extrapolating SK from other river systems.

(con'd)

Feeding requirements	No IEK for < 30% of species; IEK and SK congruent/complementary for > 75% of species; Incongruent knowledge for < 10% of species	Sampling from other river systems provided the SK for > 85% of species	Very low level of local SK and with most SK based on studies in other river systems. The high level of IEK and the high level of congruence among knowledge systems validated the extrapolation of SK from other river systems to the Daly and the lack of incongruence between SK and IEK for most species provided greater confidence in both knowledge sources.
Fish condition	No IEK for > 40% of species; IEK and SK congruent/complementary for < 50% of species; No incongruent knowledge	Sampling for this project provided the SK for > 75% of species	High level of local SK but based on limited sampling of each site. The IEK provided validation of the use of SK from short term study and complemented/extended SK for some species.

to the Daly River. Whereas such information may be considered generic at the regional scale, understanding species' distributions within the Daly River catchment required more specific local knowledge, and this yielded a high level of new knowledge from indigenous responses.

Greater confidence in the veracity of project knowledge yielded practical tools of benefit to water managers. Indigenous participants' rich knowledge of fish predation and understanding of the factors influencing flow changed the scientists' conceptual understanding of the flow ecology, and this IEK was integrated into the quantitative environmental flow risk assessment using Bayesian Belief Network (BBN) predictive models (Chan et al. 2012) for two high-risk species, i.e., black bream and barramundi. IEK influenced the structure of the model in two key ways: (1) the emphasis that Wagiman participants placed on predation and the frequency with which barramundi were identified as top predators influenced Chan et al. (2012) to include predation by barramundi as an important factor in the model; and (2) indigenous responses relating to flow, particularly low-flow characteristics, provided the researchers with further impetus to include water quality as a node in the BBN models.

Without this input, researchers would not have included a predation node or emphasized its importance because the fish ecologists on the team (B. J. Pusey and M. J. Kennard), although experienced in tropical regions, had not fully appreciated the significance of barramundi predation. In addition, indigenous participants reported greater confidence in the models knowing that their knowledge had contributed to the development of the models.

Third, a finding that both IEK and SK from the Daly were limited in some circumstances highlighted the need for more information to test the validity of extrapolating from other river systems. This was particularly true for aspects of spawning ecology, e.g., spawning habitat and substrate.

Fourth, instances of incongruence either between or within the two knowledge systems highlighted the need for more research or the need for follow-up interviews. In at least one case, it appears that differences between SK and IEK may have arisen because of confusion over the identity of a particular fish. Four of the incongruent responses given by Wagiman for the golden goby were consistent with the similar-looking sleepy cod. Although Wagiman had clearly identified these as separate species, their cryptic appearance and bottom-dwelling habit mean that they are difficult to distinguish from bankside observations; hence, uncertainty over their ecology is unsurprising. Likewise, the incongruence between different Wagiman groups relating to knowledge of golden goby and black bream warrants further investigation to identify likely reasons.

In other cases, incongruence between SK and IEK appears to have arisen from differences in the spatial scale of different knowledge sources, as described for barramundi spawning previously. Our collaboration did not work through the implications of indigenous knowledge of barramundi spawning patterns with the relevant traditional owners; however, this logical next step should be contemplated in cases where there is community interest and in which there is a sufficient degree of trust between all parties. An interesting angle to pursue would be the role of local cultural institutions in producing knowledge that might inhibit and/or enhance opportunities for sustainable management (Nursey-Bray 2003). In this case, the ontologies that are expressed frequently in local "myths" would be worthy of further examination. A number of creation stories were recounted during the project, and these included explanations of the origins of fish traits such as the shiny scales of barramundi, poisonous spines in catfish, and the distribution patterns of turtle species across the freshwater–saltwater interface. These characteristics were determined by the behavior of ancestral creator beings during a time when humans and nonhumans were beings of the same ontological kind: fish and other animals danced, walked, fought with each other, and carried out ceremonies and rituals. Acquiring knowledge from scientists who produce it through the subject–object dichotomy of Enlightenment thought (Watson and Huntington 2008) may be perceived as corrosive to the authority of indigenous experts, particularly if it conflicts with local accounts. However, it is also possible that new insights would be welcome and assimilated. Watson and Huntington's (2008:269) work on indigenous knowledge suggests that collaborative endeavors will benefit from approaches that treat such stories as "ontological assertions" rather than being dismissed as myth. Were such an approach taken, participants in a research partnership would be compelled to question what constitutes valid knowledge and what gets left out, as well as the basis for these selections.

Other benefits of integrating knowledge

In addition to enhancing the scientific understanding of fish biology and flow-ecology relationships (Stewart-Koster et al. 2011, Chan et al. 2012, Pettit et al. 2013), the research partnership generated a number of beneficial outcomes for indigenous people. First, field trips provided opportunities for people to exchange "stories about fish," including their cultural significance. Traditional owners appreciated the project's holistic approach to identifying important cultural values and to community development (Smyth 2012). Lizzie Sullivan observed that "for many old people these research trips were the first time they had a chance to see country for a long time" (Smyth 2012:14). On-site storytelling provided an opportunity to pass knowledge on to younger generations, and audiovisual recordings were made for conservation purposes. Mona Liddy, a Wagiman elder, felt that "participation of young people instilled pride and recognition in future leaders – it strengthened their spiritual ties to country, their community and identity" (Smyth 2012:13). She also found that the process of engaging in field research was beneficial in its own right because it jogged memories relating to fish and of the country (Minutes of Project Steering Committee Meeting, 20 October 2006). These perspectives suggest that further investigation of the religious and spiritual knowledge relating to fish would be productive.

Second, community members were also engaged in the project's knowledge transfer and adoption activities. For instance, the project funded indigenous participation at scientific conferences on at least three occasions. A poster of the fish found within the customary estates of the Wagiman language group was produced with corresponding language names. It was described by one local leader as "a lasting benefit of the project" (Smyth 2012:12). Elders reported feeling "very proud to show their achievements to the wider community and through presentations at conferences" (Smyth 2012:13). The researchers were also very pleased to see indigenous contributions toward achieving project results formally acknowledged in these ways.

Finally, the research assisted in building the capacity of a number of indigenous people to contribute to water planning and conservation management decisions. For instance, two of the authors, i.e., Mona Liddy and Lizzy Sullivan, are Wagiman representatives on the Daly River Management Advisory Committee, a multistakeholder group advising the NT water agency in the development of the *Draft Water Allocation Plan, Oolloo Aquifer* (NRETAS 2012). These representatives argued that "women especially would like to be involved in long term monitoring of water and wetlands" and that research can help them to fulfill responsibilities to manage national parks under their control (Smyth 2012:14). Wardaman participate directly in management decisions affecting the Flora River protected area, i.e., *Guwining* in Wardaman language, and they valued the opportunity to participate in research in that area. Given that indigenous people can be less equipped to learn more about fisheries than scientists because of the differences in access to technology and knowledge networks (Foale 2006), the partnership represented a valuable opportunity to provide resources and learn.

Ethical, cultural, and logistical challenges of designing and conducting cross-cultural research

In partnerships such as ours, integration of knowledge across cultures requires a critical recognition of the impacts of colonization on indigenous societies (Butler 2006). Indigenous people in the study region no longer spend most of the year living alongside the river, pursuing a lifestyle heavily dependent on fish and other aquatic species (see Kearney 1991, Raymond et al. 1999, Stanner 2010). The individuals we worked with were acutely aware that fish knowledge had been lost from their respective groups over recent generations and that it was continuing to erode as a result of wider social changes. Confirming the language names for some fish was difficult with only one fluent Wagiman language speaker available. On a number of occasions, participants stated that they were concerned that knowledge was not being transferred across generations as it had been in the past. Jabal Huddleston's comment illustrates this concern:

> *I ask those young fellas to come here and sit down (and listen) but they go away. They know a different language. The old people used to tell us. My grannie bin tell us, we like to listen to stories about fish. They'd say, "Who's going to carry on these stories?" ... We didn't catch up with them enough to hear those stories.* (S. E. Jackson's field notes, Chilling Billabong, 26 August 2006)

A research collaboration of this kind presents numerous challenges that can strain relationships and affect other outcomes, irrespective of the strength of researcher commitment to ethical conduct and adherence to protocols. For this reason, we will highlight a number of areas for improvement with the expectation that our experience will inform and enhance future two-way research initiatives. Like many efforts to reform research practices, we focused heavily on procedural issues (Davidson-Hunt and O'Flaherty 2007). We gave less attention to cooperative or collaborative problem framing and conceptualization, which a number of studies nominate as a critical determinant of success in knowledge integration projects involving indigenous people (Cullen-Unsworth et al. 2012, see also Casteldon et al. 2012). Had traditional owners played a stronger role in designing the research, it is likely that we would also have developed a formal mechanism for indigenous partners to review and revise drafts of findings (Koster et al. 2012) throughout the project.

The negotiation and execution of one of the research agreements required more time than any of us consider is reasonable. In one case, a bureaucratic delay of two years to execute a research agreement made it far from easy to reconcile the conflicting demands of a legally incorporated indigenous organization with the short-term funding conditions of the research project. On a more practical level, the project experienced a small number of minor difficulties characteristic of remote indigenous Australia. For example, few indigenous collaborators had bank accounts, resulting in long delays in payments to individuals. According to Mona Liddy, the difficulties that arose when attempting to confirm fish names could have been avoided had the project team included a linguist (D. Smyth, *personal communication*, 7 February 2012). These and other logistical difficulties were overcome because of the strength of the respectful and trusting relationships that were the hallmark of the collaboration.

Our experience confirms Holcombe and Gould's (2010) observation that reliance on institutional regulation and codification alone are unlikely to generate or sustain ethical and collaborative relationship with indigenous peoples. In this case, researchers and indigenous experts embarked on a process of continual dialogue and genuine negotiation that extended beyond mere adherence to procedure. The result was a set of relationships that are likely to endure beyond the life of this project and may be applied to new and emerging problems and research goals. This approach is regarded as an indicator of success by other studies (Ballard et al. 2008, Casteldon et al. 2012, Cullen-Unsworth et al.

2012) and by traditional owners closely involved in the project: "Traditional Owners felt they had ownership of the project - there was a good balance between Traditional Owners, researchers and other stakeholders" (Smyth 2012:13).

CONCLUSION

We have described a successful research partnership that combined indigenous and scientific knowledge and trialed tools to integrate project knowledge about fish and flow ecology in the context of water planning. Project results influenced the conceptual models developed by scientists to understand the flow ecology as well as the structure of risk assessment tools designed to understand the vulnerability of particular fish to low-flow scenarios. In addition to generating knowledge that confirmed field survey results, the approach we have described elicited knowledge that was new to both scientific and indigenous participants. Some differences between indigenous and nonindigenous knowledge of fish and flows was found to exist, and this was attributed to a number of factors, including observational differences, i.e., temporal and spatial, and the methodological power of field-sampling techniques relative to the ability of subsistence fishing practices to generate knowledge of relevance to wider questions about aquatic ecology. It is difficult to apportion responsibility for any empirical gaps in indigenous knowledge to each of these factors, or indeed to the significant part that colonization is likely to have played in eroding indigenous knowledge over the past 150 years. Differences between indigenous and scientific knowledge about fish will need to be closely examined in light of the specific circumstances of each case of research collaboration. At the least, conflicting accounts highlight areas for further research to test the assumptions/strength of current SK.

For the traditional owners involved in this research, accounting for the differences between the knowledge systems is of less interest than is arresting the decline in knowledge of fish and other ecological phenomena that have accompanied rapid social and economic change. For that reason, the partnership sought to document, conserve, and revitalize indigenous fish knowledge. All parties engaged in the project saw value in pursuing opportunities to "listen to stories about fish," thereby equipping indigenous landowners and water planners with the resources to apply new insights to contemporary land and water management problems.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/issues/responses.php/5874

Acknowledgments:

This project received funding from the Land and Water Australia Environmental Water Allocation Program, the NT Natural Resource Management Board, and the Tropical Rivers and Coastal Knowledge (TRaCK) research hub. TRaCK receives major funding for its research through the Australian Government's Commonwealth Environment Research Facilities initiative, the Australian Government's Raising National Water Standards Program, Land and Water Australia, the Fisheries Research and Development Corporation, and the Queensland Government's Smart State Innovation Fund. The research was done in collaboration with Wagiman, Wardaman, and Jawoyn traditional owners and the Wagiman Guwardagun Rangers, the Wagiman-Tjuwailyn women, Wardaman Association, Jawoyn Association, and the Northern Land Council. Northern Territory Fisheries Research, particularly Poncie Kurnoth, and David Wilson (Aquagreen) provided outstanding field support; David Cooper and Mark Harvey (University of Newcastle) provided a great deal of linguistic advice; and David Cooper assisted with interviews of Jawoyn traditional owners. We are grateful to Rosemary Hill from CSIRO and Courtland Smith from Oregon State University for their comments on an early draft of the paper and to reviewers for their helpful suggestions that substantially improved the manuscript.

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Activity 3c: Data Integration Questions

Watch: video: https://vimeo.com/108466803
"The enabling power of participatory 3D mapping among the Saramaccan People of Suriname"

Read: " The Bhutan Declaration"

Discuss this Declaration and Video and consider the questions below

1. How are indigenous peoples and their knowledge presented in the video?
2. How can you characterize the differences in the IK presented in the Declaration and the types of IK presented in "We Like Stories about Fish"
3. How could researchers broaden their inquiry about indigenous knowledge to include the stories and explanations of indigenous environmental ethics and values?

The Bhutan Declaration on Climate Change and Mountain Indigenous Peoples

International Network of Mountain Indigenous Peoples

Mountain Communities Workshop on Climate Change and Biocultural Heritage

26 May – 1 June 2014

We, over 100 indigenous peoples and traditional farmers from 25 communities in 10 countries speaking 22 languages, together with civil society organisations and research institutions, gathered in Bhutan in the communities of Jangbi and Ura from May 26 to June 1, 2014, to analyze the impacts of recent climatic changes on Mother Earth and on the livelihoods and cultures of indigenous peoples in mountain regions, and to develop responses to this crisis.

“Even though we are suffering disproportionately from climate change impacts, we contribute the least to global emissions”

Our communities include the Monpas and Uraps of Bhutan; the Naxi and Zhuang of China; the Kumaon, Lepcha, Limboo, Monpas, Newar and Sartang of India; the Batken, Kochkor, and Kopro-Bazar from Kyrgyzstan; the Herowana-Ubaigubi, Jiwaka and Yupna of Papua New Guinea; the Rasht Valley, Shughnan and Wakhan Valley communities of Tajikistan; Quechua communities of the Potato Park from Peru; the Mintapod community of the Philippines; the Tayal, Kanakanava and Pangcah of Taiwan; and the Pgakenyau Hinladnai of Thailand.

Our gathering took the form of a “Walking Workshop”, which provided the appropriate methods and tools for an effective exchange of ideas and experiences, the airing of common problems and a collective brainstorming on possible solutions. It included food and video festivals and direct interaction with the people of Jangbi and Ura. This creative tool for networking and promoting our special indigenous spirit and sense of mission concluded in the formation of an International Network of Mountain Indigenous Peoples. We are happy to present to the international community this promising new network on the occasion of the 14th Congress of the International Society of Ethnobiology.

We are also happy to announce that we have initiated a unique seed exchange program between the Potato Park in Peru, the communities in Yunnan, China and the Ura and Jangbi communities in Bhutan. This exchange will be expanded to other members of the network, being mindful of local ecosystems, culture and indigenous peoples’ intellectual property rights.

Mountain biocultural systems are home to many indigenous cultures and languages, and are rich but fragile repositories of cultural and biological diversity, water and other critical ecosystem services. Of unique importance are the indigenous agricultural traditions that have provided us all with important food crops critical for the food security of the world. These are the result of the traditional knowledge and innovation systems of our peoples. The survival of our knowledge systems is critical for the survival of humanity.

We found that in many mountain regions, indigenous and traditional cultures already face drastic changes in their food and agricultural systems, including changes in rainfall patterns, increased temperatures and increased pests and diseases. For example: a 50-60% decrease in water sources in the Eastern Himalayas; extreme drought in SW China; extreme rainfall in Taiwan; extreme typhoons in the Philippines; and rains arriving too late or too early in many cases. In Quechua communities, potato cultivation is moving up in altitude due to increased temperatures and pests and diseases; in Papua New Guinea animals that people depend on for food are migrating to higher levels due to increased temperatures; while unusual weather patterns are affecting forest ecology in Thailand and crops in Kyrgyzstan. As a result, the often-intimate connections between people and agricultural crops are strained, as are the community institutions, traditional values and spiritual beliefs that underpin them.

Even though we are suffering disproportionately from climate change impacts, we contribute the least to global emissions; nevertheless we have been marginalized from participating in the development and implementation of policies, programs, plans and actions related to our local adaptation.

As an emerging International Network of Mountain Indigenous Peoples concerned for the future of mountain ecosystems and the livelihoods of our communities, and in the spirit of solidarity and reciprocity, we call upon governments, research organisations, academics, civil society organisations and the international community to:

1. Recognize the sacred nature and inherent rights of Mother Earth, particularly to its diversity, richness and the welfare of all its children, including plants, animals, rivers, mountains, birds, wind, rocks, spirits, etc., and adhere to the principles of reciprocity and balance with nature, which nurtures life for everyone.

2. Acknowledge and respect the world views and cultural and spiritual values of indigenous peoples and traditional farmers, and recognize the sacred nature of their seeds.

3. Respect and promote the Biocultural Heritage rights of indigenous peoples and traditional farming communities and fully implement the UN Declaration on the Rights of Indigenous Peoples.

4. Promote the use of indigenous and traditional languages as living libraries of critical traditional knowledge associated to mountain biocultural heritage, and provide adequate funding for indigenous educational processes, learning models and pedagogical practices, involving the youth and elders in knowledge transmission.

5. Recognize the contributions of traditional knowledge to the conservation and sustainable use of mountain ecosystems and their agro-biodiversity, and support the creation and management of traditional knowledge banks that would allow us to share appropriate adaptation strategies and continue innovating.

6. Support processes for bridging traditional knowledge and science to create effective methods and solutions for the conservation and sustainable use of agro-biodiversity, food security and climate change adaptation; while respecting our right to reject the use of technologies such as Genetically Modified Organism and Geo-engineering for being an attack to the integrity of Mother Earth.

7. Support and promote cross-cultural exchanges of knowledge, innovations and technologies among indigenous and traditional farming communities from mountain ecosystems to enable them to find appropriate and effective solutions to common challenges.

8. Support activities around the International Year of Family Farming, and recognize the value and contributions of traditional agricultural systems to national food security by integrating traditional knowledge into sectoral policies, plans and programs at the national level.

9. Support seed exchanges and the repatriation of seeds from international gene banks to create more options for adaptation and ensure local food sovereignty and the food security of the world.

10. Support the strengthening of local governance, customary laws, traditional authorities, and the Wisdom and participation of elders.

We call on indigenous peoples and traditional farmers to assert their Food Sovereignty and to first and foremost give importance to the food and nutrition of our children, and we call upon national governments to fully implement the Right to Food.

Finally, we want to reaffirm our commitment to working together and in our own communities towards our goals of ensuring food sovereignty and fostering biodiversity-rich agricultural systems and the protection of our Biocultural Heritage and local rights.

“we call upon national governments to fully implement the Right to Food”

Get involved

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Left: Asociacion ANDES, Dia de la papa, Potato Park, Peru **Middle:** Praveen Chettri, Lepcha farmers, Eastern Himalayas, India **Right:** Krystyna Swiderska, Farmers' seed fair, Yunnan, Southwest China