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Article

Monitoring Outcomes of Environmental Service Provision in Low Socio-economic Indigenous Australia Using Innovative CyberTracker Technology

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Abstract

Payments for environmental services (PES) are increasingly promoted as an economic mechanism that could potentially address socio-economic and environmental conservation objectives in developing regions. However, the reporting and conditionality requirements of PES projects can be inhibitory, particularly for people with low environmental monitoring or administration capacity. Here, I provide five case studies where Indigenous Land and Sea Management groups in remote northern Australia, have combined Indigenous ecological knowledge, Western science, and the innovative CyberTracker technology to record and monitor the ecological outcomes of their land management activities to facilitate engagement with mainstream economies in Australia. The case studies elucidate methods of data collection and recording for established and potential PES projects where environmental monitoring and adaptive land and sea management are clear objectives, with longer term prospects for socio-economic benefits of Indigenous community education, empowerment and development. Similar monitoring and reporting methods could be applied in other contexts where individuals or community groups want to engage in emerging mainstream environmental service markets, but lack environmental monitoring and reporting capacity, such as other Indigenous groups, people from economically poor regions, or farmers in environmentally valuable regions.

Keywords: Indigenous ecological knowledge, capacity building, market-based instruments, citizen science, payment for environmental services

INTRODUCTION

Payments for environmental services (PES) have emerged as a potential economic mechanism to address global poverty and environmental degradation, especially in developing and remote areas with few mainstream economic opportunities (Altman et al. 2007; Bulte et al. 2008; Nelson et al. 2010; Concu Forthcoming). PES initiatives can be considered part of the broader class of market based incentives (Jack et al. 2008). Generally, PES initiatives envelope five guiding principles; these are described by Wunder (2005) as "(1) a voluntary transaction in which a well-defined (2) environmental service is (3) "bought" by a buyer from (4) a provider, if and only if the provider (5) continuously secures the provision of the service (condition)." Demonstration of continuous service provision requires monitoring of work effort (input data) and more importantly, the environmental outcomes of that work, or environmental service provided (output data) which requires substantial technical and reporting skill and often investment (Jack et al. 2008). The monitoring and reporting conditions attached to PES projects are one of the primary obstacles to attracting and securing adequate remuneration for environmental service provision

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(Wunder 2007), particularly in developing regions where the technical, administrative and organisational capacity of the population is often low (Ferraro 2001). Paradoxically, it is in developing regions that most socio-economic benefit can be gained from PES projects (Pagiola et al. 2005), especially where local communities have a history of providing environmental services, such as customary fire management by Indigenous communities in northern Australia (Yibarbuk et al. 2001; Whitehead et al. 2008; Garde et al. 2009;), without adequate remuneration (Muller 2008). Here, I present five case studies which demonstrate how Indigenous Land and Sea Management (ILSM) groups (locally known as rangers) in remote, economically poor, Arnhem Land in northern Australia (Figure 1), have used innovative monitoring techniques to measure the environmental outcomes of their land management activities which include fire, feral animal and weed management, and biodiversity and ecosystem protection. The methods deploy user-friendly techniques based on images, Indigenous language words, sounds and CyberTracker data collection technology to overcome the low Western numeracy and literacy skill set of the rangers. The versatility of the monitoring and reporting methods described allows repeatability of the methods in a broader range of contexts, including in agricultural settings, where Western scientific skills do not meet expectations of the service buyer.

Arnhem Land covers approximately 100,000 sq. km of diverse and relatively intact land in remote tropical northern Australia (Altman et al. 2007). However, like many natural ecosystems, Arnhem Land is also exposed to significant emergent environmental and biodiversity threats from future climate change, altered fire regimes, feral animals, and invasive plants (Altman et al. 2007; Garnett and Sithole 2007; Woinarski et al. 2007). Furthermore, Arnhem Land is owned, inhabited, and largely managed by a sparse population of approximately 20,000 Indigenous people who aspire to remain on and care for these, their ancestral lands, in accordance with national and international conservation objectives (Altman 2003; Altman and Whitehead 2003; Altman et al. 2007; Ens et al. 2012a). The recent voluntary declaration of Indigenous Protected Areas (IPA) within Arnhem Land by Traditional Owners is testament to the common conservation goal of local Indigenous communities

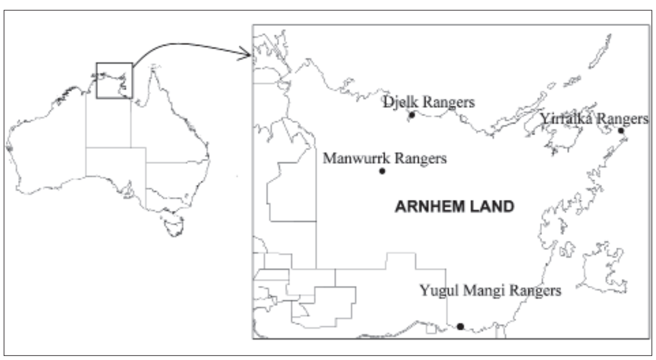

Figure 1
Map of Arnhem Land, Australia, showing the base location of the Djelk, Manwurrk, Yirralka and Yugul Mangi Rangers

and the Australian Government. Australian IPAs form part of the National Reserve System and meet one or other of the six IUCN categories of reserves (Gilligan 2006). For further information on Australian IPAs, see Ross et al. (2009) and Concu and May (Forthcoming).

In 2010, there were ten ILSM groups in Arnhem Land, all of which provided a variety of environmental services in different ways, using a complex mix of funding streams, and each with their own reporting requirements. PES-type projects conducted in Arnhem Land range from intermittent performance payment tasks to more general conservation-based activities funded by government, non-government and philanthropic agencies. Payments are made upfront, through block payments, or provided post-service (performance payment). An example of a performance payment scheme operational in Arnhem Land is the remote mosquito, marine debris and disease inspection programme of the Australian Quarantine and Inspection Service (AQIS) which provides financial reward for the completion of specific tasks (Muller 2008). In this case, monitoring of success or outcomes is quantified as the supply of discrete items or pieces of information (input data) to the service buyer, AQIS; typically, this form of service is additional, apart from the core stream of work for ILSM groups (Muller 2008). Stability and sustainability of ILSM groups generally relies on block funding through the Federal Government's "Working on Country" and "Community Development and Employment Projects" (CDEP) schemes which provide funding for employment (full-time and in the latter case, part-time positions), as well as the "Caring for our Country" grants and IPA programme funding which offer operational support for resources and infrastructure (May 2010). The "Caring for our Country" and IPA funds are tied to broader land management objectives as outlined by the ILSM group; for example, fire management or feral animal control.

Monitoring the success of environmental services is typically input-based and limited to operational indicators such as number of hours worked, area covered or animals culled (Engel et al. 2008). Ideally, payments would be made according to the "quantity" of the ecosystem service provided, or be output-based (Engel et al. 2008). However, this requires knowledge of the baseline condition against which services can be measured, including an understanding of the processes of change, environmental patterns, indicators of change, and accurate measures of environmental services provided (Tomich et al. 2004). There is limited baseline data available for the flora, fauna, abiotic conditions and ecosystem processes in Arnhem Land. Arnhem Land, by virtue of its land tenure arrangements and very remote and difficult to access location, has been relatively understudied by Western scientists compared to other parts of Australia. This lack of baseline data presents a significant challenge to ILSM groups in Arnhem Land in terms of their ability to establish accurate environmental monitoring and performance measures. It is also pertinent to mention that poor monitoring of environmental service provision outcomes is common across broader Australia (ANAO 1997, 2008; Robinson et al. 2009) and other parts of the world (Hajkowicz 2009).

The following case studies outline some of the practical approaches and technologies ILSM groups have adopted and developed with external scientific collaborators to strengthen their monitoring and reporting skills, and therefore their capacity to meet the requirements of funding bodies and PES opportunities. Of particular note is the use of innovative CyberTracker technology, which has been used to quantify and document spatial and temporal information on baseline biodiversity values, threats to country, and the specific outcomes of land management activities. A number of direct and indirect outcomes of these approaches are discussed, such as the combining of Western and Indigenous ecological knowledge; the intergenerational transfer of Indigenous ecological knowledge—which is at risk of being lost (Horstman and Wightman 2001); the acquisition of information to inform adaptive, local land management decisions; long-term monitoring of ecosystem parameters; and the empowerment of remote cash-poor Indigenous communities.

CyberTracker

CyberTracker is free software (available for free download at www.cybertracker.org.za) that was initially developed to assist the documentation of southern African San Bushmen animal tracking knowledge (Liebenberg et al. 1998; Liebenberg 2003). The software is under continual improvement, with advice, suggestions and commissioned additions from users worldwide. CyberTracker provides a framework for collection of data on a handheld Personal Digital Assistant (PDA) using words of any language, icons, and images or sounds, making it a versatile data collection tool that can cross cultural and linguistic boundaries. Among many other projects, the software has been used by Indigenous rangers with low numeracy and literacy skills in Africa (Liebenberg 2003) and Australia (Jackson et al. 2009), and in the development of scientific inquiry processes in primary school children (McDonald and Butler Songer 2008). Its additional versatility lies in its environmental adaptability: from rugged field conditions to indoor automated systems, depending on the type of PDA used.

CyberTracker software facilitates the development of a series of linked screens designed to ask a series of 'questions' or prompt recording of information, such as location, user name or a sound recording (Ens 2010). A filter function can also be applied to provide species identifications in the field. Responses to each 'question' can be customised to the skill level of the user and to facilitate entry of data that matches the project objectives. For example, users can be prompted to check either one or several multiple choice answers, type in a response, make a sound recording or take a photo.

For land management, three types of data can be collected: operational, inventory and monitoring data. Operational data refers to information on who was involved, what activities were undertaken, activity location, time and method (PES input data). Inventory data refers to records of cultural, environmental (ecosystems, communities, populations and species) and infrastructure assets (PES input or output data). For example, several Indigenous ranger groups across northern Australia use a CyberTracker sequence (referred to locally as I-Tracker) designed by the Djelk Rangers, North Australian Indigenous Land and Sea Management Alliance (NAILSMA) and the Carpentaria Ghost Nets Program, to collect data on sea country (coastal) patrol monitoring activities including domestic and foreign fishing activity, boat traffic and dead, sick or injured wildlife (Jackson et al. 2009; Ansell and Koenig 2011). CyberTracker software has also been used to monitor the condition of assets and environmental change (PES output data) using rigorous ecological methods (Ens et al. 2010); Ens et al. 2012b. Other than facilitating PES reporting, this information can also be used to inform management plans and strategies, identify strengths and weaknesses of work programmes, identify resource needs, and to report back to communities, especially when the data is collected by people involved in the PES work.

METHODS

Five different types of environmental service projects are examined: three which assess the outcomes of environmental threat management (fire, feral animals and weeds), and two related to environmental asset conservation (ecosystems and biodiversity). The examples include projects that are currently receiving remuneration, such as weed control, through to potential PES projects where baseline data are being collected to leverage future remuneration, such as wetland conservation. All case studies are based on Indigenous land management initiatives in Arnhem Land in northern Australia, with dual objectives of environmental conservation and local income generation. The case studies present examples of how monitoring and reporting techniques have been developed with and for people with low scientific and reporting skills. Despite the participatory processes involved in the development of methods and techniques, in all cases there was reliance on non-Indigenous input into the establishment, analysis and interpretation phases of the monitoring. The first case study outlines how the fire management activities of ILSM groups involved in the Western Arnhem Land Fire Abatement (WALFA) project are monitored using CyberTracker. These CyberTracker sequences were developed primarily by the non-Indigenous Djelk Ranger coordinator and the Djelk Rangers (see Ansell and Koenig 2011). The monitoring programmes outlined in the other four case studies were developed collaboratively by the author and ILSM groups, including their non-Indigenous coordinators. This work forms part of a participatory action research project involving a university researcher and ILSM groups that has been designed to collect evidence for the environmental outcomes of ILSM work in northern Australia. The case studies draw out some of the strengths and weaknesses of the methods, and the links between participatory environmental monitoring and socio-economic development—topics which are further examined in the discussion.

RESULTS: CASE STUDIES

Fire management: The Western Arnhem Land Fire Abatement project

Fire management is an integral part of conservation area management worldwide. More recently, increased importance has been placed on strategic fire management as a consequence of anthropogenic global warming and the emerging carbon market. In 2005, the WALFA project was established in Australia as an innovative carbon offset agreement between the multi-national energy company, Conoco-Phillips, and the Northern Territory Government. A further agreement was made between the Northern Territory Government and the Northern Land Council (a northern Australian Indigenous representative body) for Indigenous ranger groups, including the Djelk and Manwurrk Rangers (Figure 1), to undertake strategic burning activities. WALFA is an upfront PES project which pre-empted the establishment of a formal national carbon trading scheme in Australia. Further details of the project and the arrangements are presented elsewhere (see Whitehead et al. 2008; Russell-Smith et al. 2009a). Contemporary fire management in Arnhem Land broadly replicates customary burning practices of local Indigenous people (Yibarbuk et al. 2001; Russell-Smith et al. 2003). Hence, patchy cool season burns are implemented by a majority of ILSM groups.

Here we demonstrate how the Djelk and Manwurrk Rangers of central and western Arnhem Land have used innovative CyberTracker software to record early dry season control burns and late dry season fire fighting activities as part of the monitoring and reporting requirements of the WALFA project. These CyberTracker data are combined with information collected by the Northern Territory Government Bushfires Council and scientific partners on remotely sensed fire scars and on-ground monitoring of grass fuel loads and tree densities (Russell-Smith et al. 2009b) to quantify the carbon abatement (ecosystem service) delivered by ILSM groups' fire management programmes.

CyberTracker sequences were developed by the Djelk Rangers for control burning and fire fighting activities in the WALFA region (see also Ansell and Koenig 2011). Control burning includes both on-ground and aerial approaches to burning. The on-ground burning sequence facilitates collection of information on how fires are lit (matches, incendiaries or drip torch), where they are lit, by whom, and the duration of the burn effort. Aerial burning activities are conducted using a helicopter that is fitted with a Raindance incendiary machine. To record aerial burning activities, an automated CyberTracker sequence was developed to record exactly where and when incendiaries are dropped, the drop rate, and whether the incendiaries are defective or not. The PDA is connected directly to the Raindance machine, so that only manual selection of the user name is required. The sequence can also be adjusted to contain a map of previous seasonal fire scars (from Northern Australia Fire Information website: http://www.firenorth.org.au/nafi2/) with a preferred incendiary line overlay (Figure 2). This map can serve as a guide for strategic aerial control burns. Figure 3 depicts a Manwurrk Ranger incendiary line (black line) for a cool season control burn (white patches show remotely sensed fire scars) applied to act as a fire break around a patch of endemic, fire-sensitive and threatened sandstone heath vegetation.

The fire fighting sequence prompts recording of who is involved, the fire location and the duration of fire fighting. Following data collection and burning activities, the CyberTracker report is downloaded onto the data storage computer where a map of the region showing the incendiary line and overlaid fire scars can be viewed to assess fire management activity and efficacy (Figure 3). This information can then be incorporated into carbon abatement models and reports on PES agreements. Furthermore, information on who was burning, where and when, is also important for Indigenous Traditional Owners of country who want to be kept informed about how the rangers are managing their ancestral country

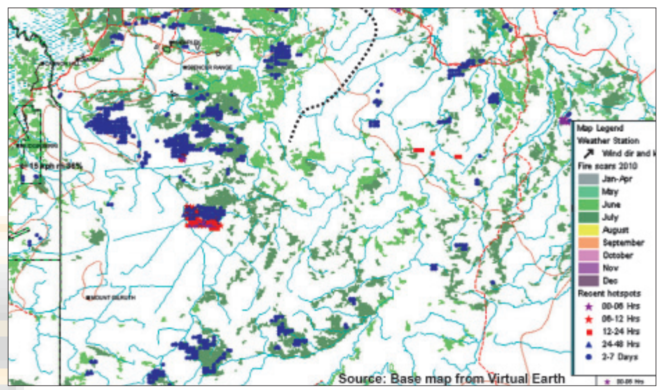

Figure 2
Fire management map with previous fire scar layers (grey patches) and an example of a preferred incendiary drop line (black dotted line)

Figure 3
Fire management map showing remotely sensed fire scars (white patches) and Manwurrk Rangers 2010 incendiary lines (black lines)

and preferably, that culturally appropriate people are directing the burning.

To facilitate collection of aerial burn activity data, the Djelk Rangers commissioned specific developments of the CyberTracker software to allow automated collection of data from the Raindance machine and enhanced mapping capabilities. The potential for specific developments or additions to the software is one of the advantages of CyberTracker. A limitation of CyberTracker use is that like most pieces of software, it does require knowledge about what data are needed, what questions could be asked to best acquire that information, computer skill to create the data collection sequence, and the ability to analyse and interpret the data in a meaningful way. Once an appropriate sequence has been created, the required abilities are in correct data entry, download, interpretation and use. However, it is still suggested that users have access to expertise in basic sequence alteration in the event that any changes are required, such as inclusion of a new site or data collector. Considering these skill requirements, communities or individuals with low numeracy and literacy skills who wish to use CyberTracker will need technical support until they have developed their own capacity. Experience has also shown that technical support needs to be readily available, particularly at the outset of the project, to avoid frustration with the technology and potential abandonment.

Feral animal management: Yirralka Rangers monitoring feral animal damage and outcomes of management

Feral animal management is one of the most difficult land management issues in conservation and agricultural sectors worldwide, particularly when the animal has an attached economic or social value. This is the case in the Laynhapuy IPA in north eastern Arnhem Land, where feral Asian water buffalo (*Bubalis bubalis*) and pigs (*Sus scrofa*) have significant environmental impacts but are also a human food resource, and offer potential economic gain for land owners through safari hunting or live export (Robinson et al. 2005; Albrecht et al. 2009; Ens and Kerins 2009). The Yirralka Rangers of the Laynhapuy IPA (Figure 1) stated that buffalo and pigs are fouling drinking water and impacting on bush tucker species such as fish, long-necked turtle (*Chelodina rugosa*), freshwater mussels (*Velesunio wilsonii*), water chestnut (*Eleocharis dulcis*) and water lilies (*Nymphaea violacea*), which are drawn on by Indigenous people as an essential food source and cultural tradition (Ens and Kerins 2009). Buffalo are typically seen as a valuable food resource (Albrecht et al. 2009) whilst pigs are not (Ens and Kerins 2009). Hence, in 2007, the Yirralka Rangers received funding from the Northern Territory Government to manage (cull) and monitor the impacts of feral pigs in parts of the Laynhapuy IPA. To achieve this aim, a feral animal impact monitoring programme was developed to assess the environmental outcomes of the PES.

The monitoring programme was developed using Western ecological monitoring design (repeated sampling at multiple sites), which incorporated Indigenous indicators of healthy and damaged country as identified by the Yirralka Rangers through an informal workshop. CyberTracker software was used to facilitate ease and accuracy of data collection for water quality and transect based information. Water quality measurements (dissolved oxygen, temperature, pH, conductivity and turbidity) were taken using automated water quality meters. Measurements were recorded in the field using a CyberTracker sequence to remove the need for pen and paper. For the transect based monitoring of ground features, a series of multiple-choice 'questions' were asked at each 1 m point along a 100 m transect enquiring about the ground moisture, ground surface feature (e.g., flat ground and pig digging) and ground cover feature (e.g., bare ground and grass). Questions and answers were written in both English and local Indigenous Yolŋu Matha language with an adjacent visual cue (image). Senior Yirralka Rangers requested that some words be written in Yolŋu Matha to educate younger rangers and non-Indigenous users in written Yolŋu language (Yolŋu Matha was only a spoken language pre-colonially). Analysis of these data required basic Microsoft Excel software skills, which coincidentally, were being taught to the Yirralka Rangers by the Batchelor Institute for Indigenous Tertiary Education. The Batchelor lecturer requested to use the feral animal monitoring data in Microsoft Excel lessons with the Yirralka Rangers as a real and local example. However, despite this training, much of the data analysis and reporting was required from non-Indigenous ranger coordinators or external scientists as the capacity of Indigenous rangers in this field was limited.

Monitoring the outcomes of the feral pig management plan provided direct evidence of an environmental service being conducted by the Yirralka Rangers. In this case, the vegetation cover increased and water quality improved when feral pigs were removed. The environmental outcomes of the project were simply assessed with the aid of CyberTracker software. Standardised data were easily collected by the rangers and laborious data entry tasks were avoided; however, external assistance was required with data analysis. Short term social benefits of the feral animal management project were also observed. They included increased confidence in reading and using technology, and improved life outlook as a result of being out on country and actively participating in the surveillance and protection of country, which is a cultural responsibility for Indigenous Australians. Some of the longer term social outcomes remain to be quantified and are more difficult to measure. However, other studies have documented the mental and physical health benefits (Burgess et al. 2005), economic development potential (Altman and Dillon 2005; Garnett and Sithole 2007) and increased opportunity to perform cultural responsibilities (caring for country) as a result of Indigenous participation in ecosystem service delivery.

Weed control: Yugul Mangi Rangers control Australian Weeds of National Significance

Invasive plants are considered the second largest threat to biodiversity after habitat clearance (Wilson 1997). Hence, payments for weed control as an ecosystem service has the potential to offer substantial employment opportunity worldwide. In southeastern Arnhem Land, the Yugul Mangi Rangers are controlling the spread of Australian Weeds of National Significance *Parkinsonia aculeata* and *Mimosa pigra* as PES work funded by the Northern Territory Government. This is a performance payment project which requires submission of a data sheet with details of the species of weed controlled, location, size of invasion, age of plants, etc. In this case, the buyer of the service only requires monitoring of the weed control itself (input data) and not the ecological outcomes of the weed control (output data), such as information about the recovery of the pre-invasion state, the possibility of re-invasion, or invasion of a secondary weed. Nevertheless, controlling the weed is a valuable environmental service which offers an otherwise impoverished community with income.

The rangers have identified several problems with the weed control project which relies on Western numeracy and literacy skills, pen and paper data entry, efficient administration and sufficient resources. As a result of these project requirements, the rangers stated that they often find it difficult to deliver the reports (data sheets) to the buyer, and hence, they are not correctly reimbursed for their environmental service work. The primary reasons are location of the work and the socio-economic status of the community. Arnhem Land lies in the wet-dry tropics where high humidity and rain co-occurs during the period of optimal weed control. Damage to the data sheets often occurs during the work period or during the often long trip back to the ranger base. The data sheets then need to be sent to the buyer, which can present another obstacle for local people, as communications are often ineffective in the region and repairs to equipment and infrastructure can be delayed. Equipment has a high damage rate due to the high amounts of dust and the decrepit nature of the infrastructure in this remote area. These factors can combine to increase the likelihood that the rangers will not get paid for the work they have done.

To overcome this problem, the rangers have developed a CyberTracker sequence to collect weed control data in the field, with assistance from the author. On return to the ranger base, the data can easily be exported into a spreadsheet and emailed to the buyer. Use of electronic data also makes saving copies easier, so that information can be resent if necessary. Payment for the environmental service is therefore streamlined, and better records can be kept using an electronic database. Improved documentation allows for more accuracy, accountability and transparency in the workplace, and improved financial management. These improvements can also aid adaptive planning and the development of a sustainable and progressive business which can be challenging in low socio-economic areas. However, similar to case study 2, development of workplace management practices, development of electronic databases and data analysis currently requires external technical assistance.

Ecosystem conservation: Arnhem Plateau aerial wetland mapping and condition assessment

Monitoring the outcomes of environmental services not only requires short term assessment of the actual work done, such as number of weeds killed, but also the longer term ecological outcomes. Ecological outcomes can be assessed from the landscape or ecosystem level to finer scale assessments based on biodiversity or abiotic parameters. The Arnhem Plateau rapid aerial wetland mapping and condition assessment project was developed by the author and Warddeken Land Management Limited (WLML), who manage approximately 14,000 sq. km of the 23,000 sq. km area of Arnhem Plateau in remote northern Australia. The plateau lies approximately 200–300 m above sea level and has very high biodiversity and conservation value (Woinarski et al. 2007). Of particular importance are the hundreds of perennial freshwater springs and associated systems which are the ecological life-blood of the plateau and surrounding plains during the long annual dry season of the tropical monsoon region of northern Australia.

The health of these spring flats is increasingly being threatened by hard-hoofed exotic buffalo and pigs (Ens et al. 2010). Since the recent re-establishment of Indigenous outstation communities on the plateau, and the creation of WLML and its on-ground works crew, the Manwurrk Rangers, there has been growing awareness and concern about the increasing negative impacts of feral buffalo and pigs on the perennial freshwater spring flats and associated systems, which hold both cultural and environmental significance. Despite this increased concern, management of feral animals on the plateau is problematic because the area is vast, remote and largely inaccessible by vehicle, both geographically and seasonally; and the feral animals are sparsely distributed, well camouflaged and hide during the day, avoiding detection. Furthermore, the human population of the plateau is extremely low, located in only a handful of small communities with only eight rangers available to cull the thousands of widely dispersed feral animals.

In response to this land management dilemma, WLML initiated the rapid aerial wetland mapping and condition assessment programme to facilitate strategic prioritisation of wetlands for feral animal culling and landscape rehabilitation—a proposed PES project. A CyberTracker sequence was developed with the author to capture qualitative information including wetland location, characteristics, condition, management action required, and the perceived urgency of action (Figure 4). The sequence was uploaded onto a handheld PDA which was used by the Indigenous rangers to enter the data during systematic helicopter reconnaissance flights over the plateau. One recorder entered wetland information using the PDA, while a second recorder used a separate Global Positioning System (GPS) unit connected to a laptop to map the outline of the wetlands as the helicopter circled its perimeter. After data collection, the GPS tracks were downloaded into the Fugawi mapping programme where data files for each wetland were attached to linked icons at the wetland locations shown on a topographic map. The data files could include videos, photos, text and spreadsheets. This method allowed construction of a visual database of wetlands laid over a topographic map, which circumvented the need for advanced Western literacy and numeracy skills, although some specific training was required.

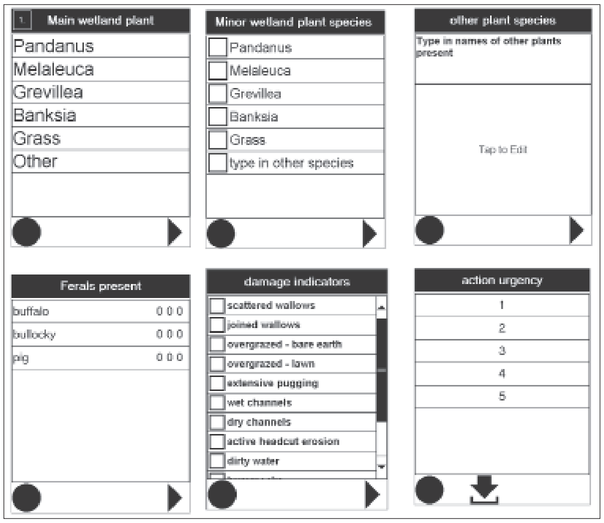

Figure 4
Examples of linked PDA screens showing parts of the Warddeken rapid aerial wetland assessment CyberTracker sequence

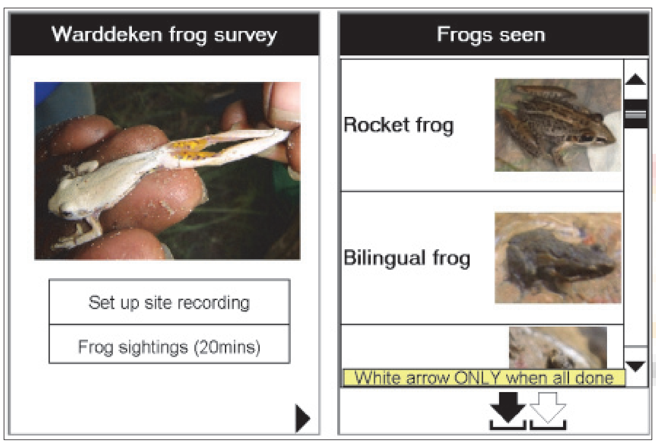

Figure 5
Home screen of Warddeken frog survey (left) and species list screen (right)

This project produced a triage system of classification to prioritise wetlands for feral cull action or landscape rehabilitation according to ranger (usually Traditional Owners of the country) perceptions of damage and urgency. There was an element of subjectivity inherent to this method; however, one of the advantages was that it incorporated Traditional Owner and Indigenous values into the system which is important for the project, considering that it is being conducted on Indigenous land for use by local Indigenous people. By collecting this baseline information, potential outcomes of the environmental services provided (feral animal cull and wetland protection and rehabilitation) could be measured, and the environmental outcomes of any payments for this service could be quantified.

Biodiversity conservation: Frog survey of the Arnhem Plateau

The environmental outcomes of PES projects can also be measured in terms of biodiversity dynamics. Frogs are internationally accepted as important indicators of ecosystem health and change (Hayes et al. 2010) and therefore have the potential to be useful indicators of environmental service provision. As far as we know, the first frog survey of the Arnhem Plateau spring flats was conducted by the Manwurrk Rangers with assistance from the author in 2009 (Ens et al. 2009). To gain an understanding of the species inhabiting the area, frog calls were recorded using a Zoom H4 recording device, and frogs were caught and photographed where possible. FileMaker Pro software was used to database all frogs recorded, including photos, calls (audio), location, recorder and notes. The Manwurrk Rangers received training in the use of FileMaker Pro software using the frog data. Following the initial scoping survey which was intended to gauge community and ranger interest as well as survey methodology, the Manwurrk Rangers embarked on a more systematic survey using CyberTracker data collection software.

Two CyberTracker sequences were developed to collect information on water quality and frog sightings or calls. The water quality sequence was used to record measurements taken by an electronic water quality meter. The frog sighting and calls sequence was used to record the GPS location of individual frog sightings or calls (Figure 5). If a frog was detected, the data collector would scroll down the list of species, click on the image of the correct frog and then tap the down arrow icon to record the GPS location (Figure 5). To facilitate identification of the frogs in the field, a local frog field guide was developed with the rangers using information and photographs collected through the participatory research (Bulliwana et al. 2009).

This project not only facilitated baseline data collection for potential payments for wetland protection and rehabilitation, but also strengthened local understanding of the environmental assets of the Warddeken IPA, and developed fine-scale environmental research capacity. As with the previous case studies, use of CyberTracker technology removed the need for pen and paper in the field and advanced Western literacy skills, as images were presented alongside words. In fact, such projects are likely to improve literacy skills by connecting images with words. Confidence in reading was also enhanced through development of the local field guide and use of other reference resources including the internet and books.

Monitoring of the frog populations of the Arnhem Plateau is an environmental service being conducted by the rangers and other interested members of the community that at the time of publication, received no specific remuneration. The frog survey provides baseline information that can be used to measure outcomes of feral animal management, wetland protection and rehabilitation projects, and also offers indicators of potential future environmental change. Monitoring for potential change is a sentinel or bio-security activity that could attract remuneration through a biodiversity credit scheme, for example. Collection of input (work effort) and output (environmental outcomes) data can facilitate more transparent remuneration and biodiversity bartering systems, which has been one of the main shortcomings of the environmental service market to date (Walker et al. 2009).

DISCUSSION

Monitoring the outcomes of environmental service delivery is difficult, especially when baseline environmental information is scant and Western skill capacity level is low. There is, however, increasing pressure for service providers to demonstrate not only the input-based, but also the output-based outcomes of funding or PES. Indigenous land and sea managers in remote Arnhem Land are increasingly receiving remuneration for environmental service provision from the public and private sectors. However, local capacity to monitor the services and outcomes of work has been limited by generally low Western literacy and numeracy capabilities, the constraints of Western reporting requirements, and a lack of baseline environmental data. Several examples are presented where Indigenous and Western knowledge systems were combined to monitor environmental service provision using innovative technologies such as CyberTracker, to overcome reading and writing obstacles and low administration capacity. Similar applications of the methodologies could be adopted in other community-based programmes which are, or could be, funded through the emergent environmental service provision or biodiversity offset markets.

Use of CyberTracker software, simple mapping programmes and other technologies has enabled ILSM groups to quantify the input-based outcomes of their activities and build baseline data from which the output-based outcomes of the service can be measured. Collection of input-based data is the most common form of PES monitoring, especially in community programmes in areas of low socio-economic status (Engel et al. 2008). From the case studies, information such as areas of weed sprayed, number of feral animals culled, hours worked, and the identity of staff working in different areas strengthened local organisational capacity and accountability. Additionally, Indigenous and non-Indigenous staff developed a greater understanding of the spatial and temporal dimensions of the environmental and cultural assets and threats to their country. Documentation of these assets and change allows for detailed examination of historical information which can be used in addition to customary knowledge, especially in areas where country has been depopulated in the recent past. This information has been used in local adaptive management planning. For example, case study 1 of the WALFA project outlined how fire management data were used to produce maps showing where and when country was burnt. The maps were then used by Traditional Owners of country and land managers to iteratively guide further burning activity and patterns according to customary burning practices. These practices not only facilitated collection of data for funding bodies and organisations, but also improved local accountability which is likely to facilitate greater community support and longevity of projects.

Collection and documentation of the outcomes of environmental service delivery provides a basis for assessment of adequate remuneration and potentially, increased economic development. In the WALFA case study, evidence of service delivery through input-based monitoring has contributed to continued support and development of this PES project. Australian government agencies have also recently advocated use of CyberTracker technology to improve ILSM group reporting on government funding. We expect that with continued use of CyberTracker by ILSM groups, PES projects will become more attractive to buyers as monitoring, accountability and reporting capacity improves. As monitoring improves, it is also likely that improved management action will follow (Danielsen et al. 2000). However, as highlighted here and by Engel et al. (2008), measurement of output data is needed to justify expansion of investment in PES projects which is a difficult task, especially when baseline data is limited.

The present case studies demonstrate how simple technologies can be used to collect baseline biodiversity and ecosystem health data. The output-based monitoring programmes adopted participatory methods to measure the recovery of wetlands after feral animal management (case studies 2 and 4) and frog diversity and abundance as indictors of ecosystem health (case study 5). Use of participatory methods which prioritise Indigenous values and interests, and two-way capacity building as both a process and goal (see Lusthaus et al. 1999; Marika et al. 2009) facilitated the uptake of these projects by the community. However, it remains to be seen whether the projects will be continued in the long term, particularly if external support is withdrawn. Other biodiversity and ecosystem health monitoring projects, such as flora and fauna surveys, could also be collaboratively developed by Indigenous land and sea managers and scientists to establish a solid baseline from which future environmental service delivery and PES projects can be measured. There is substantial potential for expansion of the PES system in Arnhem Land based on its significant biodiversity and conservation value and emergent environmental threats, as well as the need to establish culturally appropriate economic opportunity (Altman et al. 2007).

Integrity of data has often been raised as an issue in community-based natural resource management, especially where participants have limited numeracy and literacy skills (Danielsen et al. 2005; Holck 2008). However, it has also been argued that locally based monitoring can substantially contribute to environmental conservation goals, particularly in less developed regions such as the tropics, where biodiversity and environmental threats are high, and the population is sparse and largely Indigenous (Sheil and Lawrence 2004). Community-based natural resource management projects can also, however, offer socio-economic outcomes as they typically involve interacting socio-economic and environmental objectives. Hence, community projects often require context-specific and simple methods. These objectives and methods generally differ from natural resource management projects in developed regions, where technical capacity and resources are high and conservation objectives are often paramount. Despite these differences, there are many examples where community-based monitoring programmes have collected meaningful biological data (Danielsen et al. 2005). In these cases, crucial drivers of success were noted as being the continued support of Western-trained experts and use of simple, inexpensive tools and methodologies (Danielsen et al. 2003).

The present case studies illustrate how different types of data were collected using different methodologies. Objective and subjective data were collected based on questions with multiple choices, numeric, text or photo 'answers'. Most of the data were entered manually by tapping on the screen of a handheld computer to select one or more multiple choice 'answers', or by using a numeric keypad or an alphabetical keyboard. There was little room for error in much of the input based data which were primarily objective. These data included information on the names of people involved, starting a GPS track or getting specific GPS locations, or choosing from a list of weeds, chemical sprays or frogs, for example. These data were typically entered by tapping on the relevant 'choice' or button (see Figures 4 and 5). Error was more likely to occur during the collection of output-based data, such as the subjective assessment of ecosystem condition in case study 4. From these examples, there is also a possibility that error could have occurred when manually transferring information from the water quality meter or measurements from a ruler into the CyberTracker number keypad. Placement of the decimal point was one observed error that could dramatically affect the results. To try and reduce error, the format of the screens and questions were customised to meet the skill level of the users, and training in the use of technologies and information, such as water quality parameters, was provided and is ongoing. Quality control of data was exercised by the non-Indigenous support people, particularly at the outset of the projects. Obvious errors such as the misplacement of a decimal point were corrected. Other clear outliers or spurious results were omitted from data analysis, as is common scientific practice. All of the CyberTracker sequences were developed in collaboration with the users and were adaptively modified during the earlier stages of the projects to reduce potential for error and promote ease of use. The common goals of each case study were to collect baseline and monitoring data for reporting, local capacity building, and adaptive land management. Sequences were carefully designed according to these objectives.

Considering that an objective of this work was to develop the capacity of communities to autonomously manage PES type projects, an arguable weakness of the methodology is the involvement of non-Indigenous scientists, particularly in CyberTracker sequence development, data analysis and interpretation. The reliance on non-Indigenous scientists for these tasks is acknowledged, however the longer term goals of the project include local technical capacity development. Similar involvement of non-Indigenous scientists in participatory projects in the health sector has also been noted (Cashman et al. 2008). Cashman et al. (2008) also point out that often, the community or individuals do not wish to engage in data analysis and reporting activities; however, it is important to include community partners in the interpretation and synthesis of findings even if they are not fully involved in the data analysis. To engage in mainstream market economies like PES, Indigenous groups with low numeracy and literacy skills will generally require, at least initially, some external assistance to meet the reporting needs of the buyer. From this work and that of others (Lusthaus et al. 1999; Berkes 2004; Danielsen et al. 2009; Honey-Roses et al. 2009), it is evident that participatory methods which incorporate Indigenous and non-Indigenous knowledge systems, values and methods into projects offer the best chance of building local capacity and empowering local people to autonomously engage in mainstream economies in the future. With these requisites in mind, key human elements of participatory projects are suggested as: 1) community willingness to participate and improve conditions; and 2) appropriate external support people (or person) who are able to devolve power to communities, embrace mutual learning, and develop trusting and inclusive working relationships (see also Chino and DeBruyn 2006; Christopher et al. 2008). Time is also a crucial element—time to develop trust, combine knowledge and skills, transfer power, and evaluate long term project success (Ens et al. 2012a).

The technology and methodology used by ILSM groups in remote Arnhem Land, as outlined in this paper, could also be applied in other land management sectors worldwide, especially when environmental monitoring capacity is not at the level requested by the environmental service buyer, or where quick and easy monitoring methods are sought. For example, community conservation groups or farmers wanting to engage in ecosystem service provision or biodiversity offset markets could also adapt the simple and affordable, yet accurate and scientifically rigorous, CyberTracker technology to demonstrate outcomes and comply with reporting agreements. Alternative data collection tools do exist; however, they are more costly, and often require specific training and a higher level of Western numeracy, literacy and computer skills even for basic understanding (Fisher and Meyers 2011). Versatility in the type of language and form of information that can be collected using words of any language, numbers, images and sounds makes CyberTracker a user-friendly biodiversity and environmental monitoring tool for university trained ecologists through to community volunteers and Indigenous land and sea managers. These case studies show that by combining CyberTracker technology with local knowledge, values and methods, the monitoring and justification condition of the PES concept can be overcome to offer potential economic development and environmental conservation in developing regions where it is sought and arguably needed (Berkes 2004; Danielsen et al. 2009; Honey-Roses et al. 2009).

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