Rakotomahazo, Cicelin, Ravaoarinorotsihoarana, Lalao Aigrette, Randrianandrasazil Dolce, Glass, Leah, Gough, Charlotte, Boleslas Todinanahary, Gildas Georges and Gardner, Charlie J. (2019) *Participatory planning of a community-based payments for ecosystem services initiative in Madagascar's mangroves.* Ocean & Coastal Management, 175 . pp. 43-52. ISSN 0964-5691.

ARTICLE TYPE: RESEARCH PAPER

Participatory planning of a community-based payments for ecosystem services initiative in Madagascar's mangroves

Cicelin Rakotomahazo[1,2], Lalao Aigrette Ravaoarinorotsihoarana[1], Dolce Randrianandrasaziky[1], Leah Glass[1], Charlotte Gough[1], Gildas Todinanahary Georges Boleslas[2], Charlie J. Gardner[1,3]

[1] Blue Ventures Conservation, Level 2 Annex, Omnibus Business Centre, 39-41 North Road, London N7 9DP, UK. Email: cicelin@blueventures.org, lalao@blueventures.org, dolce@blueventures.org, leah@blueventures.org, charlie@blueventures.org

[2] Institut Halieutiques et de Science Marines (IH.SM), Université de Toliara, BP141 – Route du Port, Avenue de France, Toliara 601, Madagascar

[3] Durrell Institute of Conservation and Ecology (DICE), School of Anthropology and Conservation, University of Kent, Canterbury CT2 7NR, UK. Email: cg399@kent.ac.uk

* Corresponding author email: cicelin@blueventures.org

ABSTRACT

Although the dynamics of coastal resources are largely determined by the impacts of human users, spatially-explicit social data are rarely systematically integrated into coastal management planning in data-poor developing states. In order to plan a community-based mangrove payments for ecosystem services initiative in southwest Madagascar, we used two participatory approaches – public participation geographic information systems and concept modelling workshops – with 10 coastal communities to investigate the dynamics and spatial distribution of the mangrove resources they use. In each village we conducted participatory mapping of land and resource use with different livelihood groups using printed satellite images, and concept modelling workshops to develop concept models of the mangrove social-ecological system (including identification of threats and underlying drivers and proposal of targeted management strategies). Each community then proposed mangrove zoning consisting of strict conservation zones, sustainable use zones and restoration zones. Following validation and ground-truthing, the zones and management strategies proposed formed the basis of the zoning and management plan for the mangrove. Participatory approaches proved a simple and reliable way to gather spatial data and better understand the relationships between the mangrove and those who use it. Moreover, participation stimulated mangrove users to consider resource trends, the impacts of their activities, and required management actions, promoting a collective ‘buy-in’ for the project. Since participation extended beyond research to the development of management zones, rules and strategies, we believe that community ownership of the project has been strengthened and the chances of successfully conserving the mangrove improved.

Key words: Community-based natural resource management, Concept modelling, Conservation, Participatory mapping, Public participation GIS,

1. Introduction

The interactions between people and ecosystems largely determine the fate of resources, and management actions tend to target human activities (Fulton et al 2011). Thus, the importance of incorporating social data into management decision-making for natural resources in marine and coastal ecosystems is widely recognised (Cinner and David 2011; De Young et al 2008; Kittinger et al 2014). Practice, however, lags behind the theory, and social data are rarely systematically integrated into planning initiatives to the same extent as biophysical data (Le Cornu et al 2014; Moore et al 2017; St Martin and Hall-Arber 2008), in part because social data may be difficult to access in data-poor marine and coastal ecosystems (Aswani and Lauer 2006; Levine and Feinholz 2015).

One approach that can help overcome the lack of available social data is participatory research, a set of methods used to facilitate interaction and communication between researchers or decision makers and local resource users (Chambers 1997). Participatory approaches have been widely adopted in sustainable development and natural resource management since the 1970s (Bell et al 2012; Newig et al 2008), in part because they help provide the information required for planning by making use of local knowledge (Berkes et al. 2000). Moreover, when participation extends from the generation of knowledge to participation in decision making, resource management and sustainable development initiatives are more likely to be effective and enjoy greater compliance with rules (Basurto and Ostrom 2009; Brown et al 2016; Folke et al 2005). However, there remains little literature explicitly addressing how participatory research and planning are carried out in practice (Bell et al 2012), and most research on their use in marine and coastal contexts is from industrialised rather than developing countries (Koehn et al. 2013).

In this paper, we use two participatory methods – public participation GIS (geographic information systems) and concept modelling workshops – to plan the implementation of community-based payments for ecosystem services (PES) project in the mangroves of Madagascar. Mangrove forests provide a range of ecosystem services including coastal protection and erosion prevention (Alongi 2008; Dahdouh-Guebas et al. 2005), the maintenance of commercially important food species (Manson et al 2005; Nagelkerken et al 2008), the provision of timber and other provisioning ecosystem services that sustain human communities (van Bochove et al 2014), and the sequestration and storage of carbon (Lafolley and Grimsditch 2009; Nellemann et al 2009). Indeed the carbon stored in mangrove vegetation and below-ground sediment can greatly exceed that of many terrestrial forests (Donato et al 2011; Kaufmann et al 2014; Pendleton et al 2012; Wang et al 2013), but this carbon is released when mangroves are cleared; as a result, these ecosystems now garner increasing attention from PES programmes aiming to reduce atmospheric carbon through preventing the degradation or clearance of mangrove vegetation (Friess and Thompson 2016; Locatelli et al 2014).

Tahiry Honko is a community-based PES initiative that seeks to promote the sustainable use of mangroves and contribute to poverty alleviation in southwest Madagascar, through the generation and sale of carbon credits (Plan Vivo certificates, http://www.planvivo.org) on the voluntary carbon market. The sale of carbon credits is intended to finance mangrove management and provide a source of income for mangrove users, thus providing an incentive to use the forests sustainably (Blue Ventures 2014). The project was conceived and catalysed by the non-governmental organisation (NGO) Blue Ventures, and is jointly implemented by Blue Ventures and the Velondriake Association, co-managers of the Velondriake protected area in which the project is located. As part of the initial planning phase of *Tahiry Honko*, we used participatory research methods to investigate the use of mangrove resources in a spatially-explicit manner and better understand the dynamics affecting these social-ecological systems, in order to stimulate and facilitate the participatory development of mangrove zoning and a mangrove management plan.

Spatially-explicit approaches to participatory research and planning are particularly important because resource management is inherently place-based (Koehn et al 2013). As such, participatory mapping and public participation geographical information systems (a form of participatory mapping incorporating stakeholder spatial knowledge into GIS-based mapping) have been widely employed in a range of contexts for decades (McCall and Minang 2005; Norris 2014). Concept modelling forms part of the theory of change approach, which emerged in the 1990s as a tool for project evaluation in international development, (Stein and Valters 2012). It has been defined as "graphical illustration, generated in a participatory process, which represents how an intervention is expected to lead to planned outcomes through explicitly identifying causal links between outputs, intermediate outcomes and final outcomes along with the critical assumptions underlying those links" (White 2009), and is now widely used as part of the Open Standards for Conservation (CMP 2018). We use participatory mapping and concept modelling to generate complementary information on the spatial dynamics of mangrove use and the drivers of mangrove degradation as part of a participatory planning process. Our specific objectives are to i) understand the spatial distribution of land and resource use in order to develop a mangrove zoning plan, and ii) understand the pressures faced by mangroves and develop a concept model to inform and underpin the development of management strategies.

2. Methods

2.1 Study system

Madagascar harbours 2% of the world's mangroves, but suffered a 21 % reduction in their area in the period 1990-2010 (Jones et al. 2016a). Baie des Assassins (Helodrano Fagnemotse) is a coastal inlet in sub-arid southwest Madagascar (22º 11' S and 43º 12' E, Befandefa Commune, Morombe District) containing 1507 ha of mangrove forests (Fig.1) composed of seven species: *Rhizophora mucronata, Bruguiera gymnorhiza, Ceriops tagal, Avicennia marina*, *Sonneratia alba, Xylocarpus granatum* and *Lumnitzeria racemosa*. High stature, closed-canopy mangroves within the bay contain 454.92 (±26.58) MgC/ha, which is substantially lower than the global mean (Benson et al. 2017).

In 2015 the bay was inhabited by 3698 people in 10 villages (Blue Ventures 2015), primarily comprising Vezo traditional fishers who settled in the area in the 1800s (though five of the villages date only from the 1970s or more recently). Given that the region is extremely isolated and lacks transport, education and agricultural infrastructure, the community is heavily dependent on provisioning ecosystem services provided by natural habitats, which include coral reefs, seagrass beds, mangroves and adjacent terrestrial dry forest (south-western dry spiny forest-thicket, Moat and Smith 2007), for their subsistence and income. Principal livelihood activities include fishing, timber extraction and fuel wood collection, alongside agriculture, charcoal production and lime production (the burning of mollusc shells, primarily *Terebralia palustris*, to make a kind of plaster used in house construction, Scales et al 2017). Prior to the creation of the Velondriake Association some resource use was regulated through a *dina* (an informal customary institution), however this primarily concerned fisheries resources and not the mangrove. Perhaps as a result, resource extraction from the mangrove tended to be unsustainable, such that mangroves lost 3.18% of their area (net) between 2002 and 2014 (Benson et al. 2017). Although this is less than mangrove deforestation rates elsewhere in Madagascar (Jones et al 2016a, b), the net deforestation rate masks the extent of mangrove degradation within the bay, which has seen 22.4 % of closed-canopy mangrove transition to open-canopy mangrove during the same period (Benson et al. 2017).

The bay forms part of Velondriake, a 676 km^2 Locally-Managed Marine Area (LMMA) established in 2006 and formally recognised as an IUCN category V protected area within the Madagascar Protected Area System since 2015 (National decree Nº 2015-752). The LMMA is co-managed by the Velondriake Association, which is composed of representatives from 32 fishing villages, and Blue Ventures. Although three villages in the bay have been involved in local mangrove conservation since 2006, including the establishment of two temporary and one permanent mangrove closures and the implementation of local regulations (a formalised *dina*) regarding their use (Andriamalala and Gardner 2010), the scale of these initiatives was insufficient to protect the entire mangrove forest. Thus the *Tahiry Honko* project was developed in late 2013 with the 10 villages of the bay.

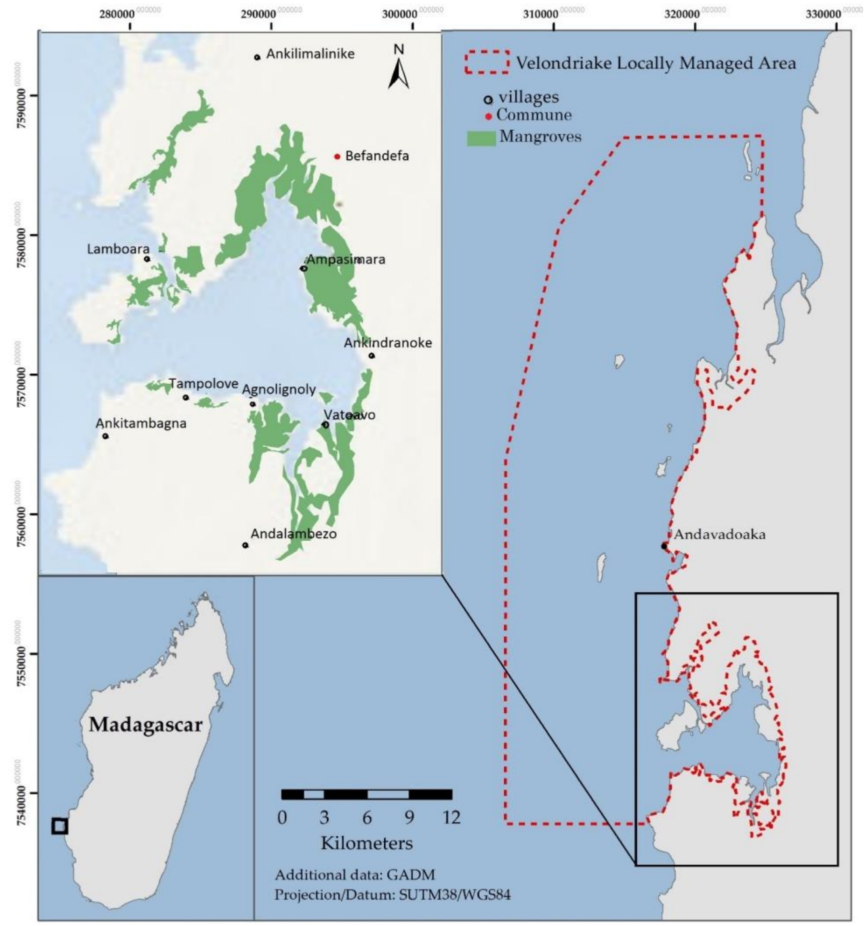

Fig. 1 Map of the study area showing the Velondriake locally-managed marine area (main map) and mangrove cover and study villages in the Baie des Assassins (top inset)

2.2 Data collection

All research was carried out by a team of five Blue Ventures staff with local villagers recruited as assistants for some exercises. The initial step consisted of courtesy visits to the president of each village, and key informant interviews with village presidents and other important residents in each of the 10 villages, in order to inform them about the objective of the work and familiarise them with the approaches to be used. Informants were asked for information about the village context, including the approximate population size, livelihood activities of villagers and the most appropriate way to conduct meetings/workshops with the local population.

2.2.1 Land and resource use mapping

We used participatory mapping to investigate the spatial distribution of land and resource use in November 2013, conducting one session in each village. In each village we recruited and trained three women to facilitate the mapping process, and held an open meeting attended by all villagers. We subsequently selected villagers to participate in focus groups on the basis of their principal livelihood activities (agriculture, fishing, lime production, timber extraction, charcoal production and fuel wood collection), with 6-10 people (including both men and women, depending on the activity) per group. We began each mapping activity by presenting a printed satellite image of the area surrounding each village to the group; these images were captured from Google Earth and showed land cover types including mangroves and adjacent dry forest. We first discussed what the images showed and how they could be interpreted, in order to assess the groups' level of understanding and their way of interpreting the images. Each group was then provided with a printed image, and asked to think about, and draw, the locations where they conduct their activities. Consensus was required for each location before it was drawn manually on the map. For each location mapped, we asked participants to answer five questions regarding i) land tenure, ii) land cover types, iii) accessibility, iv) the state of natural resources and trends in their availability over the previous five years, and v) the final destination of extracted resources. All participants in each activity group were encouraged to respond to the questions. Different coloured markers were used to better distinguish the maps drawn for each type of activity.

Following digitization of maps on Google Earth, a validation workshop was held to ensure the correct positioning of all activities and land use in the final maps. Three representatives were invited from each village, including the president of the village, one mangrove user and one dry forest user, for a total of 30 participants. During the workshop a projection of Google Earth, containing polygons representing each location drawn during the preliminary mapping exercises, was shown on a large screen (a suspended cloth). The precise boundaries of each site were discussed and validated by participants, facilitated by the interactive use of Google Earth. Use of the zoom function enabled participants to better visualise details of the area compared to the use of printed maps in the original mapping exercise, allowing us to refine each polygon with a high degree of accuracy, ensuring its correct placement using conspicuous landmarks to orientate participants.

2.2.2 Concept modelling workshops

We subsequently investigated the threats faced by mangroves and their underlying drivers through concept modelling workshops carried out in March-April 2014. We held one workshop in each village (either indoors or outdoors depending on the village context) and invited all residents; the number of participants ranged from 20 to 50 depending on the size of the village. During the process, participants were mixed in one group (men and women) to respond to the questions. Participants were asked about their perceptions of the state of mangrove resources, the direct threats acting upon them, the underlying causes of those specific threats and the strategies that could be implemented to reduce these threats. Their responses and the discussions these triggered were used to construct a conceptual model of the system on a large tarpaulin, with paper of different colours used to differentiate the state of the resource, threats, contributing factors, and potential strategies (Fig. 2). When the conceptual model was completed one representative of the community was invited to explain it, and all participants were asked to validate the final model.

Fig. 2 Participants constructing a conceptual model of mangrove resource use in the village of Lamboara (Photo: Cicelin Rakotomahazo).

2.2.3 Participatory mangrove zoning

A second participatory mapping exercise was conducted in September 2014 to develop a mangrove management zoning plan. A meeting was held in each village and all villagers were invited to attend in order to suggest the areas of mangrove they wished to allocate into conservation, sustainable management and restoration zones. As with the previous mapping exercise, participants (who ranged from 20 to 50 in number and included both men and women) were asked to draw on a printed map to delineate their preferred configuration of zones. Consensus was required from all participants before finalising the mapping of the management zone for each village.

Following digitisation of maps on Google Earth, a validation workshop was held to ensure that there were no overlaps between the maps drawn by the 10 villages. Three representatives of each village (village president and two mangrove users) attended the workshop to discuss areas of overlap, resolve potential conflicts, and validate the final maps of each management area. Direct Google Earth screen projections were again used in this session, with each site proposed being adjusted or moved according to the suggestion of the participants and finalised through consensus of all representatives of the 10 villages.

Following validation, a definitive resource use and a proposed zoning map were produced using ArcGIS (version 10.2) software. Conceptual models from each village were synthesised, and a generic model for the Baie des Assasins produced using Miradi software (Miradi version 4.2, CMP 2013).

3 Results

3.1 Land use

Participants from the 10 villages mapped 407 locations, of which 85 in the mangrove forest, 226 in the coral reef and 96 in the adjacent dry forest. These areas are used for six types of land use: agriculture, fishing, fuel wood collection, extraction of timber for housing and fencing, extraction of wood for lime production, and extraction of wood for charcoal production (Fig. 3). Mangrove forests are used for fishing, the extraction of timber for housing and fencing, fuel wood collection, and wood extraction for lime production, while the dry forest is used for agriculture, extracting timber for housing and fencing, fuel wood collection and charcoal production. No participants used the mangroves for agriculture or charcoal production, and none expressed any interest in using mangrove wood to produce charcoal. This is due to the fact that mangrove areas are frequently inundated by the tide and thus cannot be used to build charcoal kilns; thus, mangrove wood would have to be moved to a dry place to process it into charcoal, but suitable dry sites are often distant. Consequently, the dry forest is favoured for the production of charcoal. Conversely, no participants used the dry forest to extract wood for lime production. Lime producers explained that the required shells are only available in the mangrove forests, and also that mangrove wood burns with a higher intensity, thus producing a higher quality product.

With respect to land tenure, private land registration was found to be relatively low at 4% of the area mapped (Fig. 3), with most property held under customary property rights. Under the customary system, the first person to clear land is considered the owner and consequently has property rights, which may be passed on to their descendants without formalisation of the claim. Such customary private property applies only to agricultural fields, since land used for other purposes is essentially open access and can be used by any villager living around the bay. New settlers must request the right to settle from the chief of the village; if trusted by the community and accepted, newcomers then have the right to buy and rent land. Some areas ('taboo areas') cannot be owned, used for resource extraction or even entered, generally because they contain tombs or are sacred for other reasons.

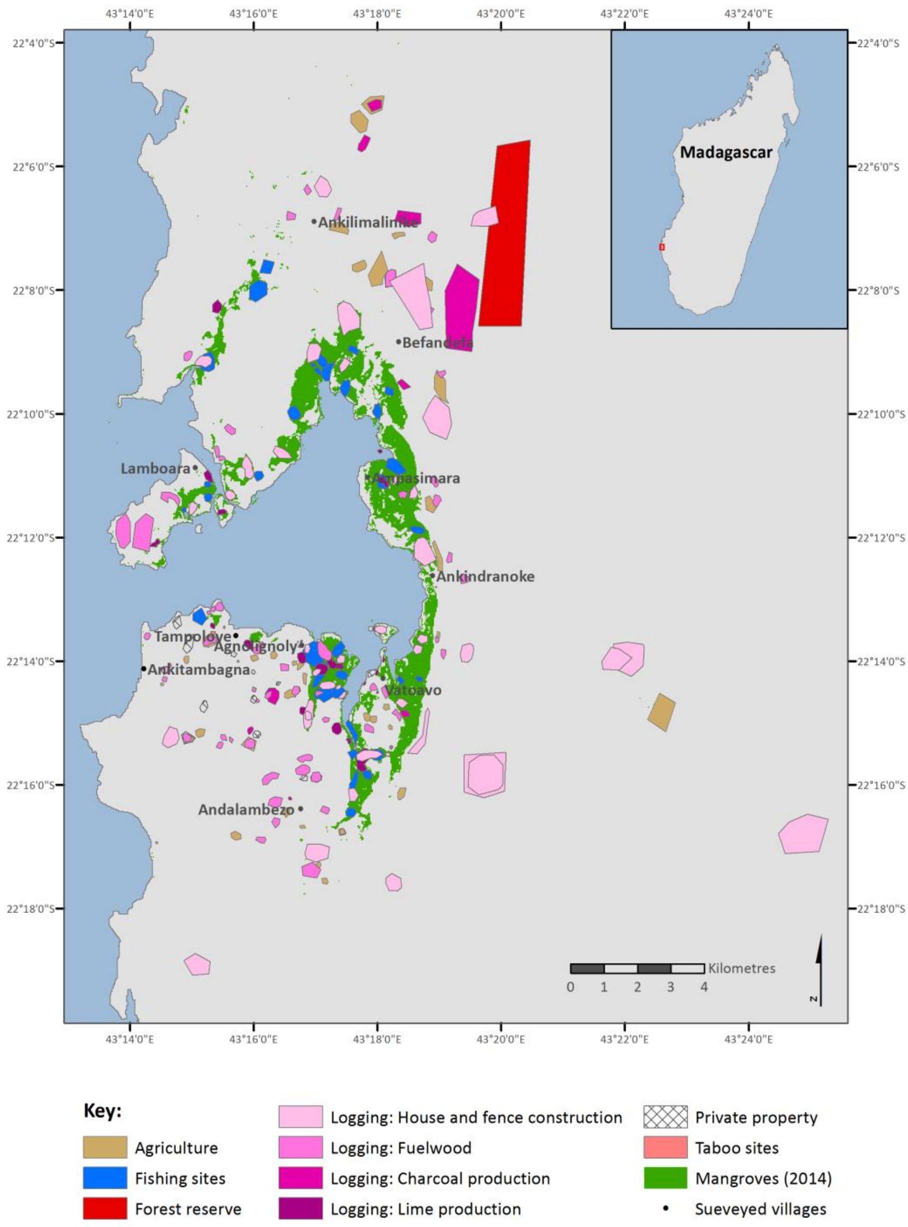

Fig. 3 Synthesised land use map for Baie des Assassins based on participatory mapping carried out in 10 marked villages. Coral reef and other marine resource uses are not mapped.

3.2. Natural resource use

Both mangroves and adjacent dry forest, as well as coral reefs, provide resources that support the livelihoods of people in all villages of the bay. In addition to providing a range of foods (finfish, crabs, shrimps, and gastropods), mangroves are an important source of wood. Mangrove wood (especially *Ceriops tagal*, *Rhizophora mucronata* and *Bruguieria gymnorhiza*) is used for most of the housing and fencing in the area, as well as providing the fuel to burn shells for lime production. However it is rarely used for fuel wood except when baking bread, because it burns at a very high temperature. Terrestrial forests are used as a source of fuel wood, wood for producing charcoal, and timber for housing. Outside of private property and taboo areas there is open access to all resources: resources from mangroves, coral reefs and terrestrial forests can be used by any resident or non-resident without requesting permission, and regardless of gender or ethnic group.

Resources extracted from the mangrove, coral reef and terrestrial forests are destined for local subsistence and commercialisation at multiple scales. Agricultural products, fuel wood and charcoal are only sold locally, but timber and lime are traded as far as Morombe (50 km to the north). Mangrove and coral reef fisheries products such as crabs, shrimps, octopus, squid, sea cucumber and fish are sold at all scales: fishers sell fish products to local collectors, who then sell the products to seafood export companies operating from the regional capital Toliara, 180 km to the south. Participants perceived mangrove fisheries resources to be in widespread decline over the last five years, noting a decrease in the catch of crabs at 94% of mapped sites, decreases in shrimp at 71% of sites, and decreases in gastropod snails at 100% of sites where they are fished.

3.3. Conceptual model of the mangrove socio-ecological system

Participants perceived the decline in mangrove resources to be due to degradation of mangrove habitat and that this arose in two ways: the unsustainable harvest of mangrove wood, and natural disasters (the destruction of mangroves by cyclones and freshwater inundation) (Fig. 4). Mangrove wood is the primary material used to build any type of house or fence in the area, because it is of good quality (strong and straight) compared to wood from the dry forest. It is also used to produce lime for use in walls and floors. About 100 mangrove logs are required to burn sufficient shells to produce 50 sacks of lime, each weighing approximately 35 kg. There is high demand for both mangrove wood and lime from villages around the bay and elsewhere in the region, due to a lack of alternative construction materials and the fact that houses made of lime are considered an indicator of wealth and status by the local population (see also Scales et al 2017). As a result of this demand, mangrove timber and lime are no longer produced simply for local subsistence but are becoming increasingly commercialised.

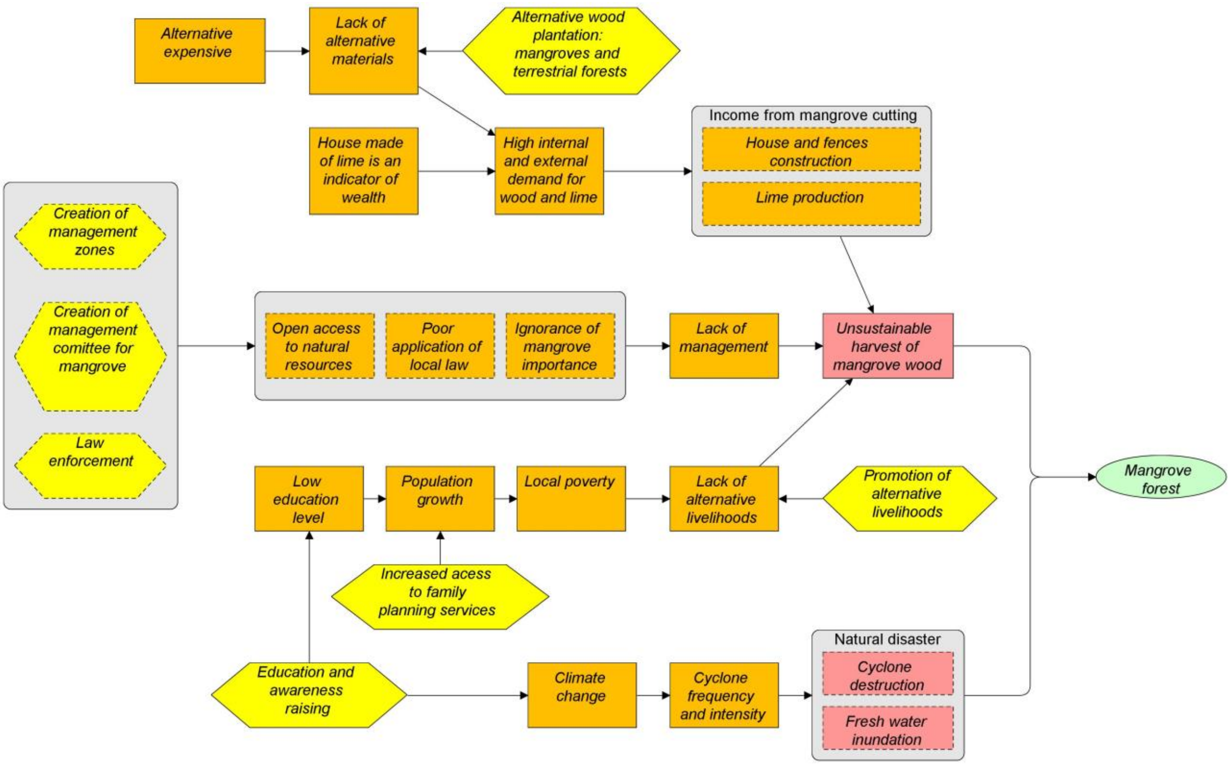

Fig. 4 Conceptual model of the mangrove socio-ecological system developed through participatory concept modelling workshops held in 10 villages of Baie des Assassins. The green box represents the targeted resource, red boxes represent direct threats and orange boxes represent underlying drivers/contributing factors. Potential strategies proposed to reduce mangrove threats are shown in yellow boxes.

3.4. Participatory zoning and management planning

Participation in the mapping and concept modelling workshops primed community members to participate in the development of a management plan for their mangroves. The mapping process enabled villagers to better understand their resource use patterns, the state and trends of these resources, and the dynamic of threats acting upon them, and also allowed them to categorise the areas with high and lower pressures that could help to identify potential areas for conservation. These processes provided the basis for each of the 10 villages to delineate three types of management zone within their mangroves: Strict conservation zones, mangrove reforestation zones and sustainable use forest management zones. In total, villagers proposed setting aside 830 ha as strict conservation zones, 1095 ha as mangrove reforestation zones and 1877 ha as sustainable use management zones (Fig. 5). This proposed zoning was then subject to ground-truthing prior to production of the definitive zoning of the mangrove. To regulate resource use within these zones, the 10 villages also agreed on a set of rules called a *dina*, a form of traditional social norm now widely used in decentralised resource management, which can be applied and enforced locally but can also be legally ratified to become a bylaw (Andriamalala and Gardner 2010; Gardner et al. 2018). The *dina* strictly prohibits i) night fishing and the cutting or collection of dead or living mangrove wood in strict conservation zones and ii) night fishing and the cutting/collection of sub-adult mangrove trees, in mangrove reforestation zones. Community members retain 'traditional use' rights to mangrove wood in the sustainable forest management areas, regulated through an annual quota allocated to households.

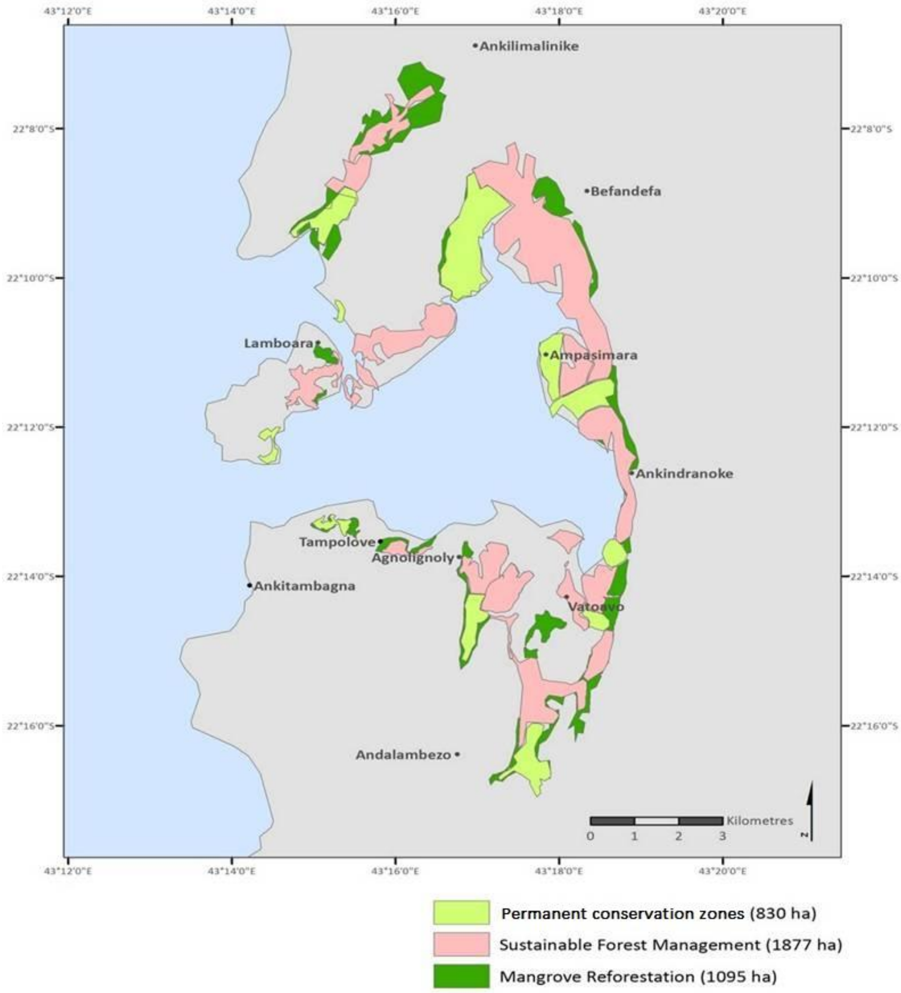

Fig. 5 Mangrove zoning for Baie des Assassins developed through participatory mapping in 10 villages.

Beyond mapping, the construction of the conceptual model linking the mangroves, threats and the underlying drivers of those threats helped community members, in conjunction with the facilitators, to define potential strategies that could be implemented to reduce the threats acting on their mangroves. In addition to zoning, suggested strategies included: alternative wood plantations (terrestrial forests), the establishment of mangrove management committees, the establishment of rule enforcement mechanisms, the promotion of alternative livelihoods, education and awareness raising, and the provision of family planning services (Fig. 4). The latter may have been suggested because Blue Ventures already manages a community health programme that provides family planning services within Velondriake (Mohan and Shellard 2014).

The establishment of management committees was considered as an important step to ensure management of designated zones. The committees will be responsible for surveillance and rule enforcement, and monitoring and evaluation of mangrove management. They will also lead awareness-raising activities to highlight the importance of mangroves within participating communities. The reforestation of both degraded/deforested mangrove areas and dry forests were also considered by participants as important strategies to help meet their high demand for wood. Although most dry forest tree species in the area are slow growing, participants understood the importance of replacing the wood that they have cut, and planned to establish plantations of *Rhizophora mucronata*, *Bruguiera gymnorhiza, Ceriops tagal* and *Avicennia marina.* The provision of family planning and education services, and the promotion of alternative livelihoods, were advanced as options that could contribute indirectly to the reduction of the threats acting on the mangroves, since low education levels, high population growth and a lack of viable livelihood choices were among the major factors considered to be contributing to the depletion of natural resources

4. Discussion

Baie des Assassins contains extensive mangrove ecosystems that have suffered high rates of deforestation and forest degradation in recent years (Benson et al. 2017) and, as such, was selected by Blue Ventures for the implementation of Madagascar's first community-based payments for ecosystem services intervention aimed at mangrove management (Blue Ventures 2014). While both the idea of a mangrove conservation programme and the funding mechanism – a carbon-based PES scheme – were conceived by a foreign NGO, we wanted to ensure that project planning was fully grounded in local social and ecological realities, and to promote local ownership of the project and participation in its activities long-term. We therefore wanted to ensure that all community members living within the project area were involved in project design as much as possible, and implemented a two-part participatory planning programme that allowed local resource users to i) map their land and resource use in order to identify the most appropriate areas for the creation of strict conservation zones, restoration zones and sustainable use zones, and ii) understand the drivers of change in the mangrove socio-ecological system and thus propose management strategies directly targeted at reducing threats.

Many (probably most) participatory exercises focus on the collection of resource use or cultural data that are then used by external (e.g. State or NGO) decision-makers to inform planning, but do not directly ask stakeholders to identify management zones or strategies themselves: participation is limited to research, but does not extend to decision-making (e.g. Brown and Fagerholm 2015; Koehn et al 2013). However, stakeholders' spatial use of a resource does not necessarily equate to their own access priorities, and the most frequented sites for resource extraction may not be the most valuable to users (Yates and Schoeman 2013). By directly asking local communities not only where they use resources, but also which areas they were willing to put under management, we directly integrated their priorities into decision-making rather than inferring them from other forms of data. Furthermore, community preferences were sought and integrated from the initial stages of the project, rather than being solicited as a validation exercise once decisions had been made, as is common in participatory processes (Jankowski 2009; Levine and Feinholz 2015). As a result, the mangrove zoning for the *Tahiry Honko* project is likely to accurately reflect local needs, increasing the probability that zoning will be respected.

We found the participatory methods we used to be appropriate and useful in the context of planning for the community-based management of natural resources, contributing to both knowledge generation and management itself. In terms of the information generated, participatory methods allowed us to make maximum use of local knowledge, generating valuable insights into the drivers of mangrove degradation and providing us with a detailed understanding of the spatial distribution of mangrove resource use in a data-poor region where information is logistically difficult to collect. Inviting all resource users to participate simultaneously allowed us to generate resource use maps for all activities combined, rather than producing separate maps for each type of resource use. The maps produced are likely to be highly accurate as participants showed great spatial understanding of the mangroves and adjacent dry forest (though see below), and were generally able to reach consensus on mapped areas quite easily. Evaluations of land cover, habitat, and species distribution maps produced using similar participatory processes in a range of contexts have shown that the maps produced by rural resource users can be highly accurate (Brown et al 2012; Cox et al 2014; Vergara-Asenjo et al 2015). In particular, the use of satellite imagery from Google Earth allowed participants to interpret the space relatively easily (compared to traditional maps) using reference points such as natural and built features, and the ability to zoom in to images, alter the angle of view and adjust polygons in real time allowed us to delineate resource use and management zones with a high degree of accuracy, while reducing the risk of transcription errors that may arise when entering data from hand-drawn maps into a GIS system (Moreno-Baez et al 2010; Yates and Schoeman 2013). Although we do not have comparative cost data, the method was also likely to be highly cost effective and rapid compared to the alternative of monitoring mangrove use and physically delineating zones on the ground with a hand-held GPS (Levine and Feinholz 2015; Ratsimbazafy et al 2016).

Beyond research, we believe that the use of participatory methods also contributed positively to the development of resource management by participating communities. The nature of the research and planning necessitated regular, close contact between the project team and a large proportion of mangrove users resident in the area, helping to establish relationships necessary to underpin the project in the long term (Thornton and Scheer 2012). The workshops also provided resource users with an opportunity to think about and better understand their own resource use and its impacts, and always stimulated lively debate about how resources should best be managed. We thus believe that they played an important role in helping to stimulate thought and build an interest in resource management amongst communities that lack any mangrove management traditions or institutions (Levine and Feinholz 2015; MacNab 2002). Similarly, discussions of potential management strategies during the concept modelling workshops may have been important in helping participants realise the potential impact of their decisions, a critical first step to implementing management amongst communities who tend to lack a belief in their own agency and ability to influence resource availability (Astuti 1995). We also believe that participation in the zoning and strategy development maximises the probability that these actions will be successful once implemented (Yates and Schoeman 2013): zoning is more likely to be respected because it was proposed by the communities themselves rather than outside actors, and the identified strategies are more likely to be successful than if they had been imposed by outsiders because they were informed by resource users' own understandings of the system (Levine and Feinholz 2015; McCall and

Minang 2005). Finally, we hope that the communities' involvement in the project from its design phase will help promote ownership of it, and adherence to its rules and actions, in the long-term (Jankowski 2009; Ramsey 2009; Smith and Berkes 1991).

Although we found diverse advantages using the two approaches, we also encountered some limitations both in terms of data collection and their practical use with the local community. Satellite images were initially quite confusing for some participants, and not intuitively easy to understand since most participants had little or no experience using maps, aerial photographs or satellite images. Thus it was necessary for workshop facilitators to spend significant time discussing how the images should be interpreted and checking participants' comprehension (see also Ratsimbazafy et al 2016). Once the images were understood participants tended to display good spatial knowledge of the mangroves they used, though they tended to be more confident and precise when mapping locations closer to the sea than in the forest, because the mangroves are almost always accessed by boat from the seaward side. In addition, differing village contexts necessitated a certain flexibility with the application of the methods, with approaches and explanations having to be tailored according to the different education levels of villages or number of participants involved. Our method required that participants reach consensus before finalising any resource use locations or management zones on the maps, but this was difficult because participants had different perspectives and levels of understanding. As a result, reaching consensus could be time consuming and sometimes generated other problems, such as anger in some participants due to the long duration of the session. In some cases participants requested monetary compensation for the time spent in participatory processes.

Implementing the work required a large team of five people, in addition to facilitators recruited in each village; the core team require good communication and facilitation skills, as well as a certain level of knowledge about the local mangrove system in order to be able to participate in discussions and orient participants. We suggest that clarity of objectives and careful planning are critical to the success of participatory approaches. At the beginning of each workshop it was important to ensure that the objectives and outputs of the work were well-understood by all participants so that everyone had a clear idea about his/her role and the expected results. In addition, the work schedule had to be coordinated with the schedules of the community involved. Villages were informed in advance and asked to advise on a convenient time to undertake the exercises, otherwise the opportunity costs of participation may be high, limiting participation to an unrepresentative sample of villagers (Scholz et al 2004; Turner and Wenninger 2005; Yates and Schoeman 2013). For coastal communities, for example, neap tide was convenient because they do not go fishing at that time. Our study also showed that participatory planning is not a single process but requires multiple visits to each community to consolidate and validate results (Campbell 2001).

In conclusion, we found participatory approaches to be particularly well-suited to the planning and development of a community-based PES programme in the mangroves of Baie des Assassins. In terms of knowledge generation, public participation GIS and concept modelling workshops generated a wealth of information about the spatial distribution of mangrove resources and livelihood activities, as well as qualitative data about the role of mangrove resources in people's lives and livelihoods, the threats mangroves face, and the underlying drivers of those threats. This research stimulated participants to consider their own agency and impacts on the mangrove social-ecological system, facilitating the subsequent participatory zoning of the mangrove and the proposal of management strategies that formed the basis of the site's management plan. Although catalysed by a foreign NGO, the project was participatory from its initial stages and the preferences of mangrove users have underpinned the development of all planning outputs, so we are confident that community ownership of the project is high, and thus that it has a strong chance of successfully conserving the mangrove.

Acknowledgements

This research was funded by the Darwin Initiative (Grant no. 19-016), the BCMAC (Grant no. 96071), the John D. and Catherine T. MacArthur Foundation (Grant no. 1509-150144 and 96071) and the Global Environmental Facility (Grant no. GFL-5060-2730-nnnn). We thank Sylvia Paulot, Katherine England and Katrina Dewar (Blue Ventures), and Tsiebo Marcelin and Guy Celestin (Institut Halieutique et des Sciences Marines), as well as the local community members who facilitated the participatory mapping and concept modelling exercises.

References

Alongi, D.M. 2008. Mangrove forests: resilience, protection from tsunamis, and responses to global climate change. Estuarine, Coastal and Shelf Science 76: 1–13.

Andriamalala, G. and Gardner, C.J. 2010. L'utilisation du dina comme outil de gouvernance des ressources naturelles: leçons tirés de Velondriake, sud-ouest de Madagascar. Tropical Conservation Science 3: 447–472.

Astuti, R 1995. People of the Sea: Identity and Descent Among the Vezo of Madagascar. Cambridge University Press, Cambridge.

Aswani, S. and Lauer, M. 2006. Incorporating fishermen's local knowledge and behavior into Geographical Information Systems (GIS) for designing marine protected areas in Oceania. Human Organization 65: 81–102.

Basurto, X. and Ostrom, E. 2009. Beyond the tragedy of the commons. Economia delle Fonti di Energia e dell'Ambiente 1: 35–60.

Bell, S., Morse, S. and Shah, R.A. 2012. Understanding stakeholder participation in research as part of sustainable development. Journal of Environmental Management 101: 13–22.

Benson, L., Glass, L., Jones, T.G., Ravaoarinorotsihoarana, L. and Rakotomahazo, C. 2017. Mangrove carbon stocks and ecosystem cover dynamics in southwest Madagascar and the implications for local management. Forests 8: 190.

Berkes, F., Colding, J. and Folke, C. 2000. Rediscovery of traditional ecological knowledge as adaptive management. Ecological Applications 10: 1251–1262.

Blue Ventures 2014. Tahiry Honko: Community mangrove carbon project, southwest Madagascar. Blue Ventures Conservation, London.

Blue Ventures 2015. Velondriake Census 2015. Available at: https://public.tableau.com/profile/charlie6654#!/vizhome/Velondriake_Census_2015_v2/VelondriakeCensus. Accessed 5th June 2018.

Brown, G. 2012. An empirical evaluation of the spatial accuracy of public participation GIS (PPGIS) data. Applied Geography 34: 289–294.

Brown, G. and Fagerholm, N. 2015. Empirical PPGIS/PGIS mapping of ecosystem services: a review and evaluation. Ecosystem Services 13: 119–133.

Brown, G., Strickland-Munro, J., Kobryn, H. and Moore, S.A. 2016. Stakeholder analysis for marine conservation planning using public participation GIS. Applied Geography 67: 77–93.

Campbell, J.R. 2001. Participatory Rural Appraisal as qualitative research: distinguishing methodological issues from participatory claims. Human Organisation 60: 380–389.

Cinner, J.E. and David, G. 2011. The human dimensions of coastal and marine ecosystems in the western Indian Ocean. Coastal Management 39: 351–357.

Chambers, R. 1997. Whose reality counts? Putting the first last. Intermediate Technology Publications, London.

CMP (Conservation Measures Partnership). 2013. Miradi: Adaptive Management Software for Conservation Projects. https://www.miradi.org/. Accessed 25th October 2017.

CMP (Conservation Measures Partnership). 2018. About open standards. http://cmp-openstandards.org/about-os/. Accessed 5th June 2018.

Cox, C., Morse, W., Anderson, C. and Marzen, L. 2014. Applying public participation geographic information systems to wildlife management. Human Dimensions of Wildlife 19: 200–214.

Dahdouh-Guebas, F., Jayatissa, L.P., di Nitto, D., Bosire, J.O., Lo Seen, D. and Koedam, N. 2005. How effective were mangroves as a defence against the recent tsunami? Current Biology 15: R443–R447.

De Young, C., Charles, A. and Hjort, A. 2008. Human dimensions of the ecosystem approach to fisheries: an overview of context, concepts, tools and methods. FAO, Rome.

Donato, D.C., Kauffman, J.B., Murdiyarso, D., Kumianto, S., Stidham, M. and Kanninen, M. 2011. Mangroves among the most carbon-rich forests in the tropics. Nature Geoscience 4: 293–297.

Folke, C., Hahn, T., Olsson, P. and Norberg, J. 2005. Adaptive governance of social–ecological systems. Annual Review of Environment and Resources 30: 441–473.

Friess D.A. and Thompson B.S. 2016. Mangrove payments for ecosystem services (PES): a viable funding mechanism for disaster risk reduction? In Renaud, F., Sudmeier-Rieux, K., Estrella, M. and Nehren, U. (Eds.) Ecosystem-Based Disaster Risk Reduction and Adaptation in Practice, pp. 75–98. Springer, Cham.

Fulton, E.A., Smith, A.D., Smith, D.C. and van Putten, I.E. 2011. Human behaviour: the key source of uncertainty in fisheries management. Fish and Fisheries 12: 2–17.

Jankowski, P. 2009. Towards participatory geographic information systems for community-based environmental decision making. Journal of Environmental Management 90: 1966–1971.

Jones, T., Glass, L., Gandhi, S., Ravaoarinorotsihoarana, L., Carro, A., Benson, L., Ratsimba, H., Giri, C., Randriamanatena, D. and Cripps, G. 2016a. Madagascar's mangroves: quantifying nation-wide and ecosystem specific dynamics, and detailed contemporary mapping of distinct ecosystems. Remote Sensing 8: 106.

Jones, T.G., Ratsimba, H.R., Carro, A., Ravaoarinorotsihoarana, L., Glass, L., Teoh, M., Benson, L., Cripps, G., Giri, C., Zafindrasilivonona, B. et al. 2016b The mangroves of Ambanja and Ambaro Bays, northwest Madagascar: historical dynamics, current status and deforestation mitigation strategy. In Diop, S., Scheren, P. and Machiwa, J. (Eds.), Estuaries: A Lifeline of Ecosystem Services in the Western Indian Ocean, pp. 67–85. Springer, Cham.

Kauffman, J.B., Heider, C., Norfolk, J. and Payton, F. 2014. Carbon stocks of intact mangroves and carbon emissions arising from their conversion in the Dominican Republic. Ecological Applications 24: 518–527.

Kittinger, J.N., Koehn, J.Z., Le Cornu, E., Ban, N.C., Gopnik, M., Armsby, M. et al. 2014. A practical approach for putting people in ecosystem-based ocean planning. Frontiers in Ecology and the Environment 12: 448–456.

Koehn, J.Z., Reineman, D.R.and Kittinger, J.N. 2013. Progress and promise in spatial human dimensions research for ecosystem-based ocean planning. Marine Policy 42: 31–38.

Laffoley, D. and Grimsditch, G. 2009. The management of natural coastal carbon sinks. IUCN, Gland.

Le Cornu, E., Kittinger, J.N., Koehn, J.Z., Finkbeiner, E.M. and Crowder, L.B. 2014. Current practice and future prospects for social data in coastal and ocean planning. Conservation Biology 28: 902–911.

Levine, A.S. and Feinholz, C.F. 2015. Participatory GIS to inform coral reef ecosystem management: mapping human coastal and ocean uses in Hawaii. Applied Geography 59: 60–69.

Locatelli, T., Binet, T., Kairo, J.G., King, L., Madden, S., Patenaude, G., Upton, C. and Huxham, M. 2014. Turning the tide: how blue carbon and payments for ecosystem services (PES) might help save mangrove forests. Ambio 43: 981–995.

MacNab, P. 2002. There must be a catch: participatory GIS in a Newfoundland fishing community. In Craig, W, Harris, T. and Weiner, D. (Eds.) Community Participation and Geographical Information Systems, pp. 173–191. Taylor and Francis, London and New York.

Manson, F.J., Loneragan, N.R., Skilleter, G.A. and Phinn, S.R. 2005. An evaluation of the evidence for linkages between mangroves and fisheries: a synthesis of the literature and identification of research directions. Oceanography and Marine Biology 43: 483–513.

McCall, M.K. and Minang, P.A. 2005. Assessing participatory GIS for community-based natural resource management: claiming community forests in Cameroon. The Geographical Journal 171: 34–356.

Miradi 2013. Adaptive management software for conservation projects. Available at www.miradi.org.

Moat, J. and Smith, P. 2007. Atlas of the Vegetation of Madagascar. Kew Publishing, Kew.

Mohan, V. and Shellard, T. 2014. Providing family planning services to remote communities in areas of high biodiversity through a population-health-environment programme in Madagascar. Reproductive Health Matters 22: 93–103.

Moore, S.A., Brown, G., Kobryn, H. and Strickland-Munro, J. 2017. Identifying conflict potential in a coastal and marine environment using participatory mapping. Journal of Environmental Management 197: 706–718.

Moreno-Báez, M., Orr, B.J., Cudney-Bueno, R. and Shaw, W.W. 2010. Using fishers' local knowledge to aid management at regional scales: spatial distribution of small-scale fisheries in the Northern Gulf of California, Mexico. Bulletin of Marine Science 86: 1–16.

Nagelkerken, I., Blaber, S.J., Bouillon, S., Green, P., Haywood, M., Kirton, L.G. et al. 2008. The habitat function of mangroves for terrestrial and marine fauna: a review. Aquatic Botany 89: 155–185.

Nellemann, C., Corcoran, E., Duarte, C.M., Valdés, L., de Young, C., Fonseca, L. et al. 2009. Blue carbon: the role of healthy oceans in binding carbon. UNEP and GRID-Arendal, Arendal.

Newig, J., Haberl, H., Pahl-Wostl, C. and Rothman, D.S. 2008. Formalised and non-formalised methods in resource management – knowledge and social learning in participatory processes: an introduction. Systemic Practice and Action Research 21: 381–387.

Norris, T.B. 2014. Bridging the great divide: state, civil society, and 'participatory' conservation mapping in a resource extraction zone. Applied Geography 54: 262–274.

Pendleton, L., Donato, D.C., Murray, B.C., Crooks, S., Jenkins, W.A., Sifleet, S. et al. 2012. Estimating global 'blue carbon' emissions from conversion and degradation of vegetated coastal ecosystems. PLoS One 7: e43542.

Ramsey, K. 2009. GIS, modeling, and politics: on the tensions of collaborative decision support. Journal of Environmental Management 90: 1972–1980.

Ratsimbazafy, H.A., Olesen, K.L., Roy, R., Raberinary, D. and Harris, A. 2016. Fishing site mapping using local knowledge provides accurate and satisfactory results: case study of octopus fisheries in Madagascar. Western Indian Ocean Journal of Marine Science 15: 1–7.

Scales, I.R., Friess, D.A., Glass, L. and Ravaoarinorotsihoarana, L. 2017. Rural livelihoods and mangrove degradation in south-west Madagascar: lime production as an emerging threat. Oryx. doi:10.1017/S0030605316001630

Scholz, A., Bonzon, K., Fujita, R., Benjamin, N., Woodling, N., et al. 2004. Participatory socioeconomic analysis: drawing on fishermen's knowledge for marine protected area planning in California. Marine Policy 28: 335–349.

Smith, A.H. and Berkes, F. 1991. Solutions to the ''Tragedy of the Commons'': Sea urchin management in St Lucia, West Indies. Environmental Conservation 18: 131–136.

St Martin, K. and Hall-Arber, M. 2008. The missing layer: geo-technologies, communities, and implications for marine spatial planning. Marine Policy 32: 779–786.

Stein, D. and Valters, C. 2012. Understanding theory of change in international development. London School of Economics, London.

Thornton, T.F. and Scheer, A.M. 2012. Collaborative engagement of local and traditional knowledge and science in marine environments: a review. Ecology and Society 17: 8.

Turner, M. and Weninger, Q. 2005. Meetings with costly participation: an empirical analysis. Review of Economic Studies 553: 247–268.

van Bochove, J., Sullivan, E. and Nakamura, T. (Eds.). (2014). The importance of mangroves to people: a call to action. UNEP-WCMC, Cambridge.

Vergara-Asenjo, G., Sharma, D. and Potvin, C. 2015. Engaging stakeholders: assessing accuracy of participatory mapping of land cover in Panama. Conservation Letters 8: 432–439.

Wang, G., Dongsheng, G., Peart, M.R., Chen, Y. and Peng, Y. 2013. Ecosystem carbon stocks of mangrove forest in Yingluo Bay, Guangdong Province of south China. Forest Ecology and Management 310: 539–546.

White, H. 2009. Theory-based Impact Evaluation: Principles and Practice. International Initiative for Impact Evaluation, New Delhi.

Yates, K.L. and Schoeman, D.S. 2013. Spatial access priority mapping (SAPM) with fishers: a quantitative GIS method for participatory planning. PLoS One 8: e68424.