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

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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

34 images, and concept modelling workshops to develop concept models of the mangrove
35 social-ecological system (including identification of threats and underlying drivers and
36 proposal of targeted management strategies). Each community then proposed mangrove
37 zoning consisting of strict conservation zones, sustainable use zones and restoration zones.
38 Following validation and ground-truthing, the zones and management strategies proposed
39 formed the basis of the zoning and management plan for the mangrove. Participatory
40 approaches proved a simple and reliable way to gather spatial data and better understand the
41 relationships between the mangrove and those who use it. Moreover, participation stimulated
42 mangrove users to consider resource trends, the impacts of their activities, and required
43 management actions, promoting a collective ‘buy-in’ for the project. Since participation
44 extended beyond research to the development of management zones, rules and strategies, we
45 believe that community ownership of the project has been strengthened and the chances of
46 successfully conserving the mangrove improved.

47

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

50

51 1. Introduction

52 The interactions between people and ecosystems largely determine the fate of resources, and
53 management actions tend to target human activities (Fulton et al 2011). Thus, the importance
54 of incorporating social data into management decision-making for natural resources in marine
55 and coastal ecosystems is widely recognised (Cinner and David 2011; De Young et al 2008;
56 Kittinger et al 2014). Practice, however, lags behind the theory, and social data are rarely
57 systematically integrated into planning initiatives to the same extent as biophysical data (Le
58 Cornu et al 2014; Moore et al 2017; St Martin and Hall-Arber 2008), in part because social
59 data may be difficult to access in data-poor marine and coastal ecosystems (Aswani and Lauer
60 2006; Levine and Feinholz 2015).

61

62 One approach that can help overcome the lack of available social data is participatory
63 research, a set of methods used to facilitate interaction and communication between
64 researchers or decision makers and local resource users (Chambers 1997). Participatory
65 approaches have been widely adopted in sustainable development and natural resource
66 management since the 1970s (Bell et al 2012; Newig et al 2008), in part because they help

67 provide the information required for planning by making use of local knowledge (Berkes et
68 al. 2000). Moreover, when participation extends from the generation of knowledge to
69 participation in decision making, resource management and sustainable development
70 initiatives are more likely to be effective and enjoy greater compliance with rules (Basurto
71 and Ostrom 2009; Brown et al 2016; Folke et al 2005). However, there remains little
72 literature explicitly addressing how participatory research and planning are carried out in
73 practice (Bell et al 2012), and most research on their use in marine and coastal contexts is
74 from industrialised rather than developing countries (Koehn et al. 2013).

75

76 In this paper, we use two participatory methods – public participation GIS (geographic
77 information systems) and concept modelling workshops – to plan the implementation of
78 community-based payments for ecosystem services (PES) project in the mangroves of
79 Madagascar. Mangrove forests provide a range of ecosystem services including coastal
80 protection and erosion prevention (Alongi 2008; Dahdouh-Guebas et al. 2005), the
81 maintenance of commercially important food species (Manson et al 2005; Nagelkerken et al
82 2008), the provision of timber and other provisioning ecosystem services that sustain human
83 communities (van Bochove et al 2014), and the sequestration and storage of carbon (Lafolley
84 and Grimsditch 2009; Nellemann et al 2009). Indeed the carbon stored in mangrove
85 vegetation and below-ground sediment can greatly exceed that of many terrestrial forests
86 (Donato et al 2011; Kaufmann et al 2014; Pendleton et al 2012; Wang et al 2013), but this
87 carbon is released when mangroves are cleared; as a result, these ecosystems now garner
88 increasing attention from PES programmes aiming to reduce atmospheric carbon through
89 preventing the degradation or clearance of mangrove vegetation (Friess and Thompson 2016;
90 Locatelli et al 2014).

91

92 *Tahiry Honko* is a community-based PES initiative that seeks to promote the sustainable use
93 of mangroves and contribute to poverty alleviation in southwest Madagascar, through the
94 generation and sale of carbon credits (Plan Vivo certificates, <http://www.planvivo.org>) on the
95 voluntary carbon market. The sale of carbon credits is intended to finance mangrove
96 management and provide a source of income for mangrove users, thus providing an incentive
97 to use the forests sustainably (Blue Ventures 2014). The project was conceived and catalysed
98 by the non-governmental organisation (NGO) Blue Ventures, and is jointly implemented by
99 Blue Ventures and the Velondriake Association, co-managers of the Velondriake protected
100 area in which the project is located. As part of the initial planning phase of *Tahiry Honko*, we

101 used participatory research methods to investigate the use of mangrove resources in a
102 spatially-explicit manner and better understand the dynamics affecting these social-ecological
103 systems, in order to stimulate and facilitate the participatory development of mangrove
104 zoning and a mangrove management plan.

105

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

124

125 **2. Methods**

126 *2.1 Study system*

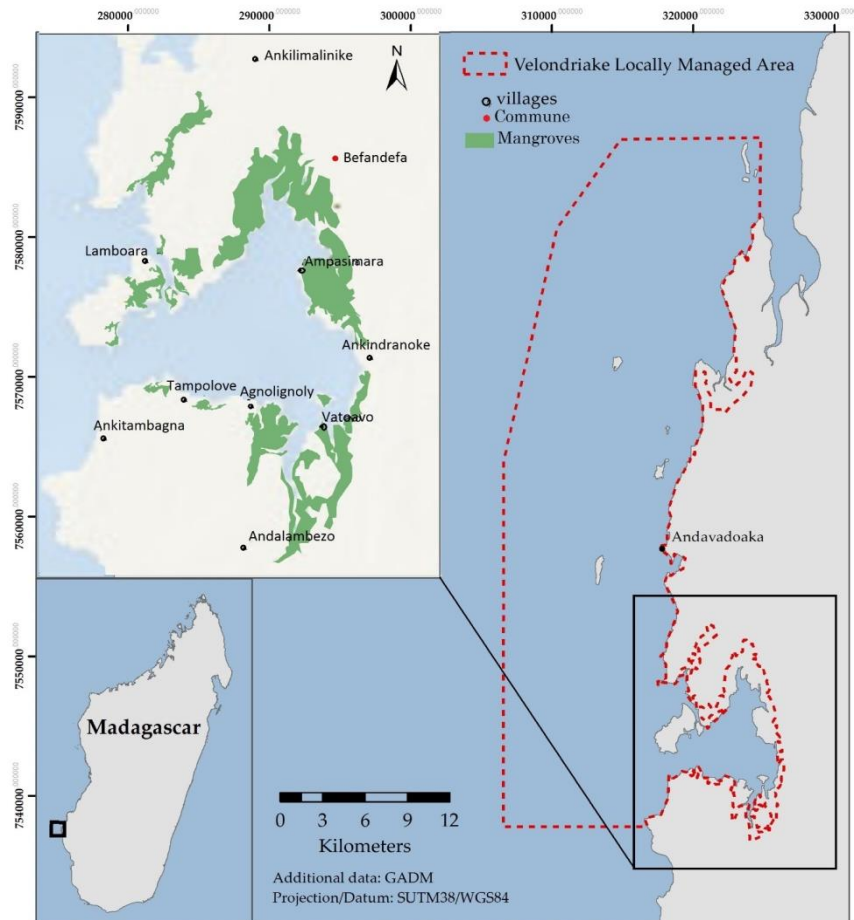
127 Madagascar harbours 2% of the world’s mangroves, but suffered a 21 % reduction in their
128 area in the period 1990-2010 (Jones et al. 2016a). Baie des Assassins (Helodrano
129 Fagnemotse) is a coastal inlet in sub-arid southwest Madagascar (22° 11' S and 43° 12' E,
130 Befandefa Commune, Morombe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

135

136 In 2015 the bay was inhabited by 3698 people in 10 villages (Blue Ventures 2015), primarily
137 comprising Vezo traditional fishers who settled in the area in the 1800s (though five of the
138 villages date only from the 1970s or more recently). Given that the region is extremely
139 isolated and lacks transport, education and agricultural infrastructure, the community is
140 heavily dependent on provisioning ecosystem services provided by natural habitats, which
141 include coral reefs, seagrass beds, mangroves and adjacent terrestrial dry forest (south-
142 western dry spiny forest-thicket, Moat and Smith 2007), for their subsistence and income.
143 Principal livelihood activities include fishing, timber extraction and fuel wood collection,
144 alongside agriculture, charcoal production and lime production (the burning of mollusc
145 shells, primarily *Terebralia palustris*, to make a kind of plaster used in house construction,
146 Scales et al 2017). Prior to the creation of the Velondriake Association some resource use
147 was regulated through a *dina* (an informal customary institution), however this primarily
148 concerned fisheries resources and not the mangrove. Perhaps as a result, resource extraction
149 from the mangrove tended to be unsustainable, such that mangroves lost 3.18% of their area
150 (net) between 2002 and 2014 (Benson et al. 2017). Although this is less than mangrove
151 deforestation rates elsewhere in Madagascar (Jones et al 2016a, b), the net deforestation rate
152 masks the extent of mangrove degradation within the bay, which has seen 22.4 % of closed-
153 canopy mangrove transition to open-canopy mangrove during the same period (Benson et al.
154 2017).

155

156 The bay forms part of Velondriake, a 676 km² Locally-Managed Marine Area (LMMA)
157 established in 2006 and formally recognised as an IUCN category V protected area within the
158 Madagascar Protected Area System since 2015 (National decree N° 2015-752). The LMMA
159 is co-managed by the Velondriake Association, which is composed of representatives from
160 32 fishing villages, and Blue Ventures. Although three villages in the bay have been involved
161 in local mangrove conservation since 2006, including the establishment of two temporary and
162 one permanent mangrove closures and the implementation of local regulations (a formalised
163 *dina*) regarding their use (Andriamalala and Gardner 2010), the scale of these initiatives was
164 insufficient to protect the entire mangrove forest. Thus the *Tahiry Honko* project was
165 developed in late 2013 with the 10 villages of the bay.



166

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

169

170 **2.2 Data collection**

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

179

180 **2.2.1 Land and resource use mapping**

181 We used participatory mapping to investigate the spatial distribution of land and resource use
 182 in November 2013, conducting one session in each village. In each village we recruited and

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

200

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

212

213 ***2.2.2 Concept modelling workshops***

214 We subsequently investigated the threats faced by mangroves and their underlying drivers
215 through concept modelling workshops carried out in March-April 2014. We held one
216 workshop in each village (either indoors or outdoors depending on the village context) and

217 invited all residents; the number of participants ranged from 20 to 50 depending on the size of
218 the village. During the process, participants were mixed in one group (men and women) to
219 respond to the questions. Participants were asked about their perceptions of the state of
220 mangrove resources, the direct threats acting upon them, the underlying causes of those
221 specific threats and the strategies that could be implemented to reduce these threats. Their
222 responses and the discussions these triggered were used to construct a conceptual model of
223 the system on a large tarpaulin, with paper of different colours used to differentiate the state
224 of the resource, threats, contributing factors, and potential strategies (Fig. 2). When the
225 conceptual model was completed one representative of the community was invited to explain
226 it, and all participants were asked to validate the final model.
227



228
229 **Fig. 2** Participants constructing a conceptual model of mangrove resource use in the village
230 of Lamboara (Photo: Cicelin Rakotomahazo).
231

232 ***2.2.3 Participatory mangrove zoning***

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

239 zones. Consensus was required from all participants before finalising the mapping of the
240 management zone for each village.

241

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

249

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

254

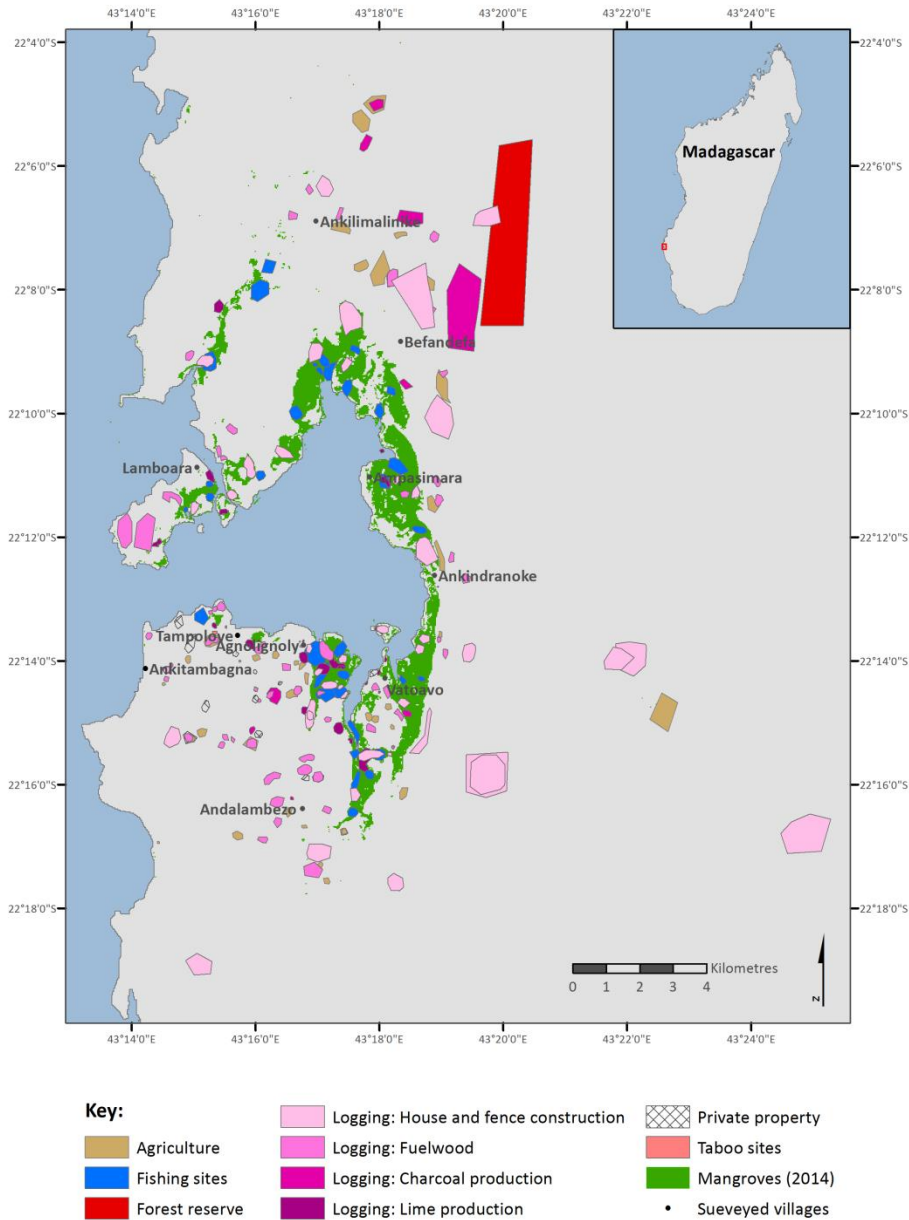
255 **3 Results**

256 ***3.1 Land use***

257 Participants from the 10 villages mapped 407 locations, of which 85 in the mangrove forest,
258 226 in the coral reef and 96 in the adjacent dry forest. These areas are used for six types of
259 land use: agriculture, fishing, fuel wood collection, extraction of timber for housing and
260 fencing, extraction of wood for lime production, and extraction of wood for charcoal
261 production (Fig. 3). Mangrove forests are used for fishing, the extraction of timber for
262 housing and fencing, fuel wood collection, and wood extraction for lime production, while
263 the dry forest is used for agriculture, extracting timber for housing and fencing, fuel wood
264 collection and charcoal production. No participants used the mangroves for agriculture or
265 charcoal production, and none expressed any interest in using mangrove wood to produce
266 charcoal. This is due to the fact that mangrove areas are frequently inundated by the tide and
267 thus cannot be used to build charcoal kilns; thus, mangrove wood would have to be moved to
268 a dry place to process it into charcoal, but suitable dry sites are often distant. Consequently,
269 the dry forest is favoured for the production of charcoal. Conversely, no participants used the
270 dry forest to extract wood for lime production. Lime producers explained that the required
271 shells are only available in the mangrove forests, and also that mangrove wood burns with a
272 higher intensity, thus producing a higher quality product.

273

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



284

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

287

288 **3.2. Natural resource use**

289 Both mangroves and adjacent dry forest, as well as coral reefs, provide resources that
 290 support the livelihoods of people in all villages of the bay. In addition to providing a range of
 291 foods (finfish, crabs, shrimps, and gastropods), mangroves are an important source of wood.
 292 Mangrove wood (especially *Ceriops tagal*, *Rhizophora mucronata* and *Bruguieria*
 293 *gymnorhiza*) is used for most of the housing and fencing in the area, as well as providing the
 294 fuel to burn shells for lime production. However it is rarely used for fuel wood except when

295 baking bread, because it burns at a very high temperature. Terrestrial forests are used as a
296 source of fuel wood, wood for producing charcoal, and timber for housing. Outside of private
297 property and taboo areas there is open access to all resources: resources from mangroves,
298 coral reefs and terrestrial forests can be used by any resident or non-resident without
299 requesting permission, and regardless of gender or ethnic group.

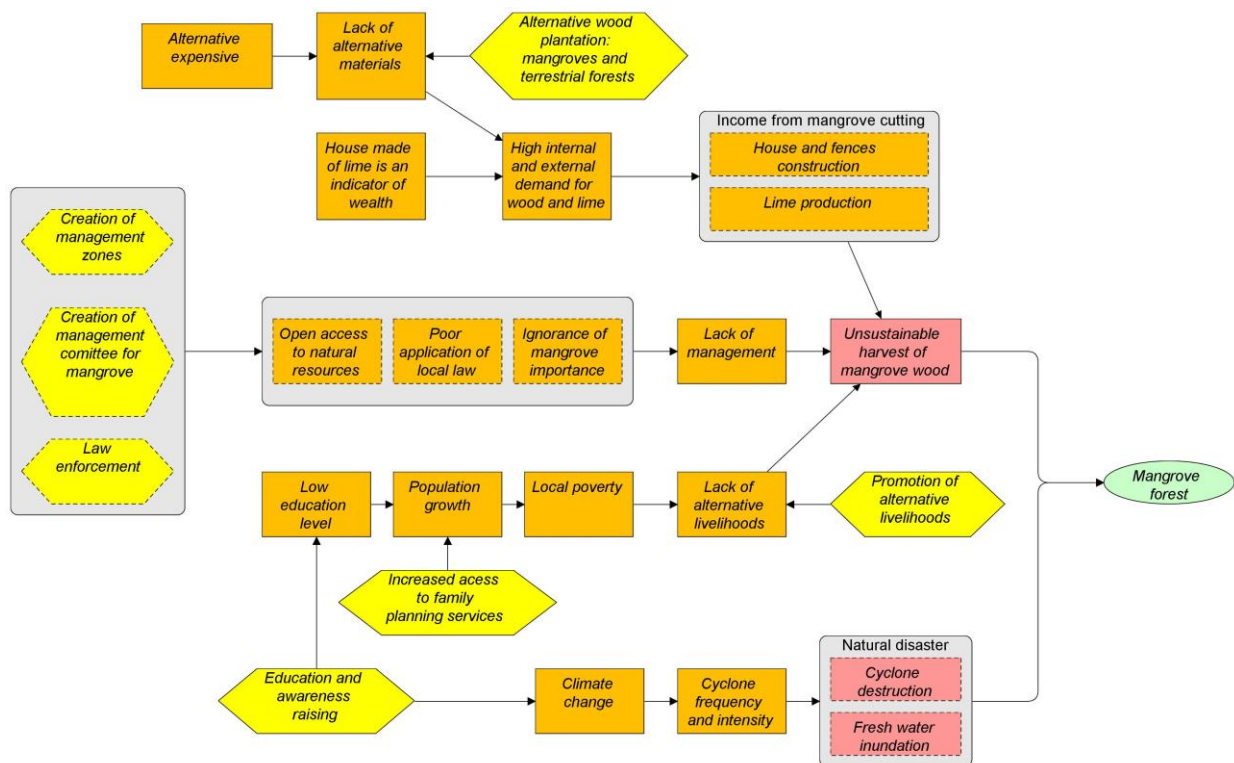
300

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

311

312 ***3.3. Conceptual model of the mangrove socio-ecological system***

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



326

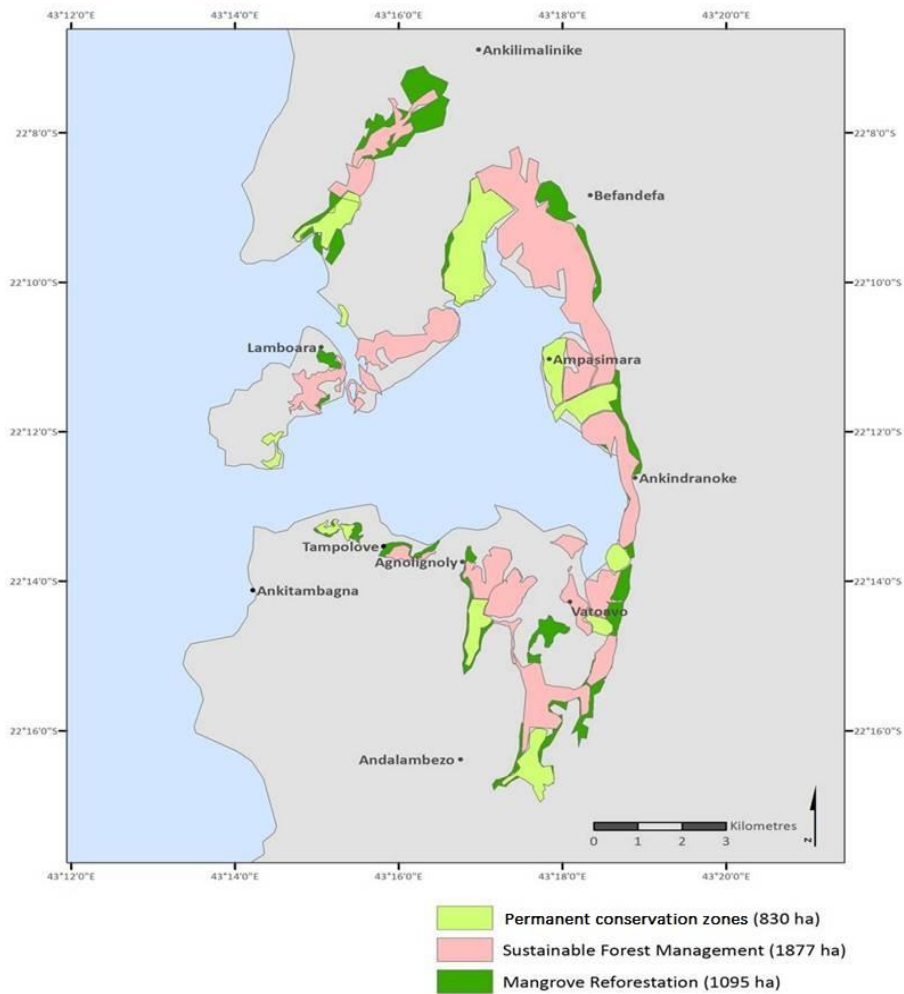
327 **Fig. 4** Conceptual model of the mangrove socio-ecological system developed through
 328 participatory concept modelling workshops held in 10 villages of Baie des Assassins. The
 329 green box represents the targeted resource, red boxes represent direct threats and orange
 330 boxes represent underlying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

332

333 **3.4. Participatory zoning and management planning**

334 Participation in the mapping and concept modelling workshops primed community members
 335 to participate in the development of a management plan for their mangroves. The mapping
 336 process enabled villagers to better understand their resource use patterns, the state and trends
 337 of these resources, and the dynamic of threats acting upon them, and also allowed them to
 338 categorise the areas with high and lower pressures that could help to identify potential areas
 339 for conservation. These processes provided the basis for each of the 10 villages to delineate
 340 three types of management zone within their mangroves: Strict conservation zones, mangrove
 341 reforestation zones and sustainable use forest management zones. In total, villagers proposed
 342 setting aside 830 ha as strict conservation zones, 1095 ha as mangrove reforestation zones
 343 and 1877 ha as sustainable use management zones (Fig. 5). This proposed zoning was then
 344 subject to ground-truthing prior to production of the definitive zoning of the mangrove. To
 345 regulate resource use within these zones, the 10 villages also agreed on a set of rules called a

346 *dina*, a form of traditional social norm now widely used in decentralised resource
 347 management, which can be applied and enforced locally but can also be legally ratified to
 348 become a bylaw (Andriamalala and Gardner 2010; Gardner et al. 2018). The *dina* strictly
 349 prohibits i) night fishing and the cutting or collection of dead or living mangrove wood in
 350 strict conservation zones and ii) night fishing and the cutting/collection of sub-adult
 351 mangrove trees, in mangrove reforestation zones. Community members retain ‘traditional
 352 use’ rights to mangrove wood in the sustainable forest management areas, regulated through
 353 an annual quota allocated to households.



354
 355

356 **Fig. 5** Mangrove zoning for Baie des Assassins developed through participatory mapping in
 357 10 villages.

358

359 Beyond mapping, the construction of the conceptual model linking the mangroves, threats
 360 and the underlying drivers of those threats helped community members, in conjunction with
 361 the facilitators, to define potential strategies that could be implemented to reduce the threats

362 acting on their mangroves. In addition to zoning, suggested strategies included: alternative
363 wood plantations (terrestrial forests), the establishment of mangrove management
364 committees, the establishment of rule enforcement mechanisms, the promotion of alternative
365 livelihoods, education and awareness raising, and the provision of family planning services
366 (Fig. 4). The latter may have been suggested because Blue Ventures already manages a
367 community health programme that provides family planning services within Velondriake
368 (Mohan and Shellard 2014).

369

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

384

385 **4. Discussion**

386

387 Baie des Assassins contains extensive mangrove ecosystems that have suffered high rates of
388 deforestation and forest degradation in recent years (Benson et al. 2017) and, as such, was
389 selected by Blue Ventures for the implementation of Madagascar's first community-based
390 payments for ecosystem services intervention aimed at mangrove management (Blue
391 Ventures 2014). While both the idea of a mangrove conservation programme and the funding
392 mechanism – a carbon-based PES scheme – were conceived by a foreign NGO, we wanted to
393 ensure that project planning was fully grounded in local social and ecological realities, and to
394 promote local ownership of the project and participation in its activities long-term. We
395 therefore wanted to ensure that all community members living within the project area were

396 involved in project design as much as possible, and implemented a two-part participatory
397 planning programme that allowed local resource users to i) map their land and resource use in
398 order to identify the most appropriate areas for the creation of strict conservation zones,
399 restoration zones and sustainable use zones, and ii) understand the drivers of change in the
400 mangrove socio-ecological system and thus propose management strategies directly targeted
401 at reducing threats.

402

403 Many (probably most) participatory exercises focus on the collection of resource use or
404 cultural data that are then used by external (e.g. State or NGO) decision-makers to inform
405 planning, but do not directly ask stakeholders to identify management zones or strategies
406 themselves: participation is limited to research, but does not extend to decision-making (e.g.
407 Brown and Fagerholm 2015; Koehn et al 2013). However, stakeholders' spatial use of a
408 resource does not necessarily equate to their own access priorities, and the most frequented
409 sites for resource extraction may not be the most valuable to users (Yates and Schoeman
410 2013). By directly asking local communities not only where they use resources, but also
411 which areas they were willing to put under management, we directly integrated their priorities
412 into decision-making rather than inferring them from other forms of data. Furthermore,
413 community preferences were sought and integrated from the initial stages of the project,
414 rather than being solicited as a validation exercise once decisions had been made, as is
415 common in participatory processes (Jankowski 2009; Levine and Feinholz 2015). As a result,
416 the mangrove zoning for the *Tahiry Honko* project is likely to accurately reflect local needs,
417 increasing the probability that zoning will be respected.

418

419 We found the participatory methods we used to be appropriate and useful in the context of
420 planning for the community-based management of natural resources, contributing to both
421 knowledge generation and management itself. In terms of the information generated,
422 participatory methods allowed us to make maximum use of local knowledge, generating
423 valuable insights into the drivers of mangrove degradation and providing us with a detailed
424 understanding of the spatial distribution of mangrove resource use in a data-poor region
425 where information is logistically difficult to collect. Inviting all resource users to participate
426 simultaneously allowed us to generate resource use maps for all activities combined, rather
427 than producing separate maps for each type of resource use. The maps produced are likely to
428 be highly accurate as participants showed great spatial understanding of the mangroves and
429 adjacent dry forest (though see below), and were generally able to reach consensus on

430 mapped areas quite easily. Evaluations of land cover, habitat, and species distribution maps
431 produced using similar participatory processes in a range of contexts have shown that the
432 maps produced by rural resource users can be highly accurate (Brown et al 2012; Cox et al
433 2014; Vergara-Asenjo et al 2015). In particular, the use of satellite imagery from Google
434 Earth allowed participants to interpret the space relatively easily (compared to traditional
435 maps) using reference points such as natural and built features, and the ability to zoom in to
436 images, alter the angle of view and adjust polygons in real time allowed us to delineate
437 resource use and management zones with a high degree of accuracy, while reducing the risk
438 of transcription errors that may arise when entering data from hand-drawn maps into a GIS
439 system (Moreno-Baez et al 2010; Yates and Schoeman 2013). Although we do not have
440 comparative cost data, the method was also likely to be highly cost effective and rapid
441 compared to the alternative of monitoring mangrove use and physically delineating zones on
442 the ground with a hand-held GPS (Levine and Feinholz 2015; Ratsimbazafy et al 2016).

443

444 Beyond research, we believe that the use of participatory methods also contributed positively
445 to the development of resource management by participating communities. The nature of the
446 research and planning necessitated regular, close contact between the project team and a large
447 proportion of mangrove users resident in the area, helping to establish relationships necessary
448 to underpin the project in the long term (Thornton and Scheer 2012). The workshops also
449 provided resource users with an opportunity to think about and better understand their own
450 resource use and its impacts, and always stimulated lively debate about how resources should
451 best be managed. We thus believe that they played an important role in helping to stimulate
452 thought and build an interest in resource management amongst communities that lack any
453 mangrove management traditions or institutions (Levine and Feinholz 2015; MacNab 2002).
454 Similarly, discussions of potential management strategies during the concept modelling
455 workshops may have been important in helping participants realise the potential impact of
456 their decisions, a critical first step to implementing management amongst communities who
457 tend to lack a belief in their own agency and ability to influence resource availability (Astuti
458 1995). We also believe that participation in the zoning and strategy development maximises
459 the probability that these actions will be successful once implemented (Yates and Schoeman
460 2013): zoning is more likely to be respected because it was proposed by the communities
461 themselves rather than outside actors, and the identified strategies are more likely to be
462 successful than if they had been imposed by outsiders because they were informed by
463 resource users' own understandings of the system (Levine and Feinholz 2015; McCall and

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

467

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

487

488 Implementing the work required a large team of five people, in addition to facilitators
489 recruited in each village; the core team require good communication and facilitation skills, as
490 well as a certain level of knowledge about the local mangrove system in order to be able to
491 participate in discussions and orient participants. We suggest that clarity of objectives and
492 careful planning are critical to the success of participatory approaches. At the beginning of
493 each workshop it was important to ensure that the objectives and outputs of the work were
494 well-understood by all participants so that everyone had a clear idea about his/her role and
495 the expected results. In addition, the work schedule had to be coordinated with the schedules
496 of the community involved. Villages were informed in advance and asked to advise on a
497 convenient time to undertake the exercises, otherwise the opportunity costs of participation

498 may be high, limiting participation to an unrepresentative sample of villagers (Scholz et al
499 2004; Turner and Wenninger 2005; Yates and Schoeman 2013). For coastal communities, for
500 example, neap tide was convenient because they do not go fishing at that time. Our study also
501 showed that participatory planning is not a single process but requires multiple visits to each
502 community to consolidate and validate results (Campbell 2001).

503

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

518

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