# Understanding livelihoods for protected area management: insights from Northern Madagascar

## ABSTRACT

Protected areas (PA) are the most common approach to conservation globally; however, their effectiveness is unclear when neighbouring human communities are highly natural resource dependent. While forest-based livelihoods provide important income for rural communities, destructive livelihoods such as charcoal production can also threaten the sustainability of PAs. We aimed to understand drivers of livelihood choices in communities surrounding a proposed PA threatened by charcoal production in northern Madagascar, to inform management strategies that promote forest conservation without negatively impacting local communities. We used semi-structured interviews and focus groups to understand local livelihood dynamics using the Sustainable Livelihoods Framework (SLF). Our findings showed charcoal production to be an important livelihood used to deal with annual food insecurity. Agricultural yields were limited by a lack of assets for clearing land and building protective fences. Households were also hesitant to invest in agriculture due to the perceived risks associated with unpredictable rainfall and cattle grazing. Furthermore, while fishing was an important livelihood for filling income gaps, declining catches due to overexploitation across the study region appeared to be increasing the need for charcoal production. While improvements to agriculture were perceived to be promising strategies for reducing forest-dependence, a landscape approach to conservation in the region will be necessary in order to promote sustainability of all livelihoods and to reduce overall pressures on forest resources.

Key words: charcoal, food security, deforestation, dry forests, fisheries, sustainable livelihoods framework, management effectiveness

## 1. INTRODUCTION

As biodiversity and forest cover decrease across the globe (Butchart et al. 2010), protected areas (PAs) are becoming increasingly implemented and now cover 15% of land and 7% of the oceans (WDPA 2018). However, their effectiveness in conserving biodiversity is debated (Geldmann et al. 2013), and they are additionally contested on ethical grounds, particularly in developing countries rich in biodiversity (Naughton-Treves et al. 2005) where restrictions on access to natural resources can inflict high socioeconomic impacts on rural communities (Pullin et al. 2013; Neudert et al. 2017). The poorest households in rural communities often depend on natural resources as safety nets to help them recover from unexpected shocks or fill gaps during the agricultural off-season, but also for building assets to invest in other livelihoods (Zulu and Richardson 2013; Angelsen et al. 2014; Jones et al. 2016). Given that people lacking alternatives may continue to illegally use resources from within PAs in the absence of effective enforcement (Holmes 2007), it is essential for PA managers to understand the factors driving livelihood choices in surrounding communities if PAs are to be effectively managed without exacerbating poverty.

This is particularly true for Madagascar, a global conservation priority harbouring an unparalleled richness of threatened endemic species (Brooks et al. 2006) alongside large rural populations highly dependent on natural resources for subsistence and income (Scales 2014), and which has been rapidly expanding and evolving its protected area system over the last two decades. Prior to 2003 all PA's in Madagascar were managed as strict protected areas (IUCN

categories I, II and IV) in which human habitation and all extractive uses of natural resources were forbidden, however the expanded PA system includes new sites managed as multiple-use PAs (IUCN categories III, V and VI) which are zoned to permit the continuation of rural livelihood activities if these are carried out at sustainable levels (Marcus and Kull 1999; Gardner et al. 2013, 2018). Thus, while the management of strict PAs focused on preventing livelihood activities through enforcement (in some cases with 'compensation' offered in the form of integrated conservation and development projects), the management of new protected areas is complex because these sites are expected to conserve biodiversity and cultural heritage while simultaneously promoting poverty alleviation and rural development (Gardner et al. 2013).

Rural communities in Madagascar typically have diverse livelihood portfolios, which can include a mix of small-scale subsistence agriculture, cash crop cultivation, livestock herding, charcoal production, timber harvesting, collection of non-timber forest products (NTFPs), artisanal mining, collection of marine products, fishing and/or bush meat hunting (Ackermann 2003; Cartier 2009; Golden 2009; Narozanski et al. 2011; Gardner and Davies 2014; Harvey et al. 2014; Gardner et al. 2016a). Diversification, and particularly a reliance on forest-based livelihoods such as charcoal production (Casse et al. 2004; Gardner et al. 2016a), is a common strategy for dealing with vulnerability and risk (Hänke and Barkmann 2017). However, the extent of household reliance on forests varies because livelihood choices depend on a complex suite of ecological, economic, political and cultural factors (Scales 2014). Such factors can include: the distance to forest, roads or markets (Urech et al. 2015), household demographics and asset status (Neudert et al. 2015), local taboos (*fady*), informal (*dina*) or formal community regulations (Gardner et al. 2008; Reuter et al. 2018; Ward et al. 2018), ethnic group (Ackermann 2003), local social cohesion (Urech et al. 2015), migrant or resident status (Nawrotzki et al.

2012), agricultural seasonality and poor yields (Harvey et al. 2014) or regional/national policies and institutions (Scales 2014).

Understanding the factors driving livelihood choices is essential for the effective management of Madagascar's PAs because livelihoods such as shifting cultivation (Casse et al. 2004), charcoal production (Gardner et al. 2016a), timber harvesting (Burivalova et al. 2015) and livestock rearing (Waeber et al. 2015) drive deforestation and degradation across the country, including in PAs (Gardner et al. 2018). Charcoal production is of particular concern due to high urban demand coupled with the informality of the sector, making regulation difficult (Minten et al. 2013). The production of charcoal from remaining natural forests is an important livelihood for many rural communities (Ackermann 2003; Casse et al. 2004; Gardner et al. 2016a) but has negative impacts on biodiversity (Gardner et al. 2016b); it therefore poses a significant challenge for PAs, which largely occur in areas where local people are heavily natural resource-dependent (Virah-Sawmy et al. 2014). Given that rural populations are predicted to grow rapidly (Harris et al. 2012) and that most remaining forests have been incorporated into the country's expanded PA system (Gardner et al. 2018), understanding how to reconcile conservation with the livelihood needs of local communities will be essential in order to increase PA effectiveness. Ideally, an understanding of local socioecological systems and resource use should be developed prior to PA establishment, in order to plan and mitigate for future changes resulting from management (Urech at al. 2015)..

Here, we seek to understand livelihood dynamics within communities surrounding a proposed PA threatened by charcoal production in northern Madagascar, to inform management strategies that promote forest conservation without negatively impacting local communities. This is particularly important as the needs and perceptions of local communities and conservation

practitioners may be very different, with different goals surrounding the aim of 'sustainability' or 'success' in their everyday endeavours (Keller 2008). We aim to determine how current livelihood choices relate to natural resources, how the PA is perceived to affect these choices and how, if at all, constraints in livelihoods affect dependency on forest resources (particularly for charcoal production). We also investigate how livelihoods could be supported to reduce charcoal production, and end by recommending management interventions to promote sustainable development and conservation in the long-term. To answer these questions, we apply the sustainable livelihoods framework (SLF; DFID 1999) to investigate the factors driving livelihood choices across three villages in the region. The SLF acknowledges the complex suite of socioeconomic, political and ecological factors influencing rural livelihoods (Fisher et al. 2013) and, therefore, can serve as a useful tool for prioritising actions to reduce livelihood constraints, and identifying important links within the socioecological system for informing policy and management (Ellis 2000).

## 2. METHODS

### 2.1 Study Site

The proposed Bobaomby PA is located northwest of Antsiranana in northern Madagascar (Fig 1). The landscape consists of fragments of secondary dry deciduous forest and littoral forest (both highly-threatened vegetation types that are under-represented in Madagascar's PA network, Waeber et al. 2015), within a matrix of anthropogenic wooded savannah of low biodiversity value. The surrounding coastal area consists of Antsiranana Bay to the east and the Nosy Hara Marine Protected Area (MPA) to the west, and comprises mangroves, mudflats and

coral reefs. The region experiences a wet and dry season, with the 980 mm of annual rain predominantly falling between January and May. The PA project was initiated in 2018 by multiple promoters including the Malagasy conservation non-governmental organization Madagasikara Voakajy and the University of Antsiranana, in collaboration with the Regional Director of the Ministry of Environment and Sustainable Development (MEDD). The area boasts high herpetofaunal diversity and populations of the endangered crowned lemur (*Eulemur coronatus*) (Mitchell et al. 2007; IUCN 2018), however the forests are highly threatened by charcoal production and cattle grazing (Mitchell et al. 2007). Previous surveys in the region found increased levels of charcoal production as rainfall and agricultural productivity has been declining, leading to localized clearing of trees (Mitchell et al. 2007). The PA is proposed as an IUCN category V multiple-use PA in which the sustainable use of natural resources is permitted, and will be co-managed by The University of Antsiranana and local community associations with support from Madagasikara Voakajy. While the area does not yet have protected status, multiple forest fragments are already managed by community forest management associations (COBA) created through joint forest management legislation (Pollini et al. 2014) and some communities also manage their marine environment through local fishers' associations (CLPs).

[FIGURE 1]

At the time of this study, Bobaomby PA was in the preliminary stage of obtaining temporary protected status, a process requiring the development of a social safeguards plan to identify and mitigate any negative impacts on local communities (Virah-Sawmy et al. 2014). Preliminary socioeconomic surveys carried out as part of this process in January-April 2018 identified 10 villages across the PA that, due to their use of forest resources, could be affected by its creation. Of these, we selected three villages for further research, based on their shared use of one of the

158 largest remaining forest fragments (Beantely), and differences in factors that may influence their
159 livelihoods, such as COBA rules, level of isolation and local taboos (Table 1). This comparative
160 analysis across villages allows a thorough assessment of the factors driving livelihood choices in
161 the region and the potential impacts of the proposed PA.

162 [TABLE 1]

163

164 **2.2 Data Collection**

165 We conducted field research over 7 to 10 days in each village during May 2018, using a
166 combination of semi-structured household interviews, key informant interviews, and focus
167 groups. Key informant interviews with local leaders allowed us to obtain an overview of
168 livelihoods, resource use and resource management in each village, while household interviews
169 provided more in-depth information about particular livelihoods. We used purposive sampling
170 for the household interviews, using information from local leaders and preliminary surveys to
171 select interviewees representing different geographical sectors, livelihoods, genders and ages.
172 Interviews were carried out in the local dialect of Malagasy by BIV, KA and a local research
173 assistant familiar with the communities. Interviews were conducted in respondents' homes, at
174 times most convenient to them. Questions focused on individual livelihood choices and the
175 factors driving them, how livelihoods related to the forest, how a PA could affect livelihood
176 choices, and whether and how respondents could envision reducing their forest use. Following
177 household interviews in each village, we used further interviews with leaders and/or households
178 to crosscheck information or clear up uncertainties. Focus groups were conducted in Malagasy
179 near the end of the research in each village by HA and a local research assistant, with additional

assistance from BIV and KA. These were conducted at the village's administrative office on days when it is taboo to work, to encourage higher turnout. Focus groups were used to complement information gathered during interviews, and focused on i) how households with different livelihoods perceived a PA affecting them, and ii) potential development interventions or PA investments that could reduce their need for forest resources (particularly charcoal production). We obtained Free, Prior and Informed Consent from all participants, anonymised all responses, and abided by the ethical codes of conduct of the American Anthropological Association and Madagascar Conservation & Development Journal (Wilmé et al. 2016). Ethical approval was also obtained from the University of Kent Ethics Committee.

### 2.3 Data Analysis and the Sustainable Livelihoods Framework

We used the SLF for structuring the analysis of the qualitative data (Ellis 2000). The framework assumes that an individual's livelihood choices are based on their access to human, physical, natural, financial and social assets. Asset availability is influenced by an individual's vulnerability, such as seasonality of income or natural disasters, and by regional and national policies and institutions, including laws, markets or cultural norms. Understanding where and why assets are lacking across populations could contribute to the development of livelihood support programmes (Nawrotzki et al. 2012), making the SLF directly applicable to PA planning. We thematically coded data from interviews and focus groups using the categories of assets, aspects of vulnerability and structures and processes used in the SLF using Nvivo Pro 11 software (Fig 2), and coded interviewees for anonymity (e.g. VAI1, VBI1). We then produced a

conceptual model of factors leading to the unsustainable use of natural resources to assist in identifying potential intervention points.

## 3. RESULTS

We completed 40 household interviews, 10 key informant interviews and three focus groups across the three study villages. The analysis revealed multiple livelihood constraints contributing to increasing forest dependence.

### 3.1 Livelihood strategies and land-use

Across the three villages, households typically had diverse livelihood portfolios, including some mix of agriculture, livestock rearing, fishing and/or charcoal production (Table SI). The majority of livelihood activities took place in the wooded savannah, locally termed the *fondra*, which also made up the largest proportion of the landscape. The savannah was used for agriculture, which consisted mainly of small-scale subsistence maize and irrigated rice production on flat land, and livestock rearing, which primarily involved raising and/or milking zebu cattle. Cattle were typically kept within fenced paddocks or tethered close to houses during the night, and left to graze freely during the day. Trees and dead wood were also collected within the savannah for cooking, building fences and charcoal production. Households usually cooked with wood collected from the savannah, thus charcoal was typically only produced for sale in Antsiranana. This is with the exception of households in BAIE, where production for sale was prohibited. Fishers typically collected marine products within the mangroves or fished within the bays or

along the shoreline, using nets and/or pirogue canoes. Fishing was carried out for both subsistence and trade; however, trade was carried out locally or within Antsiranana and there was no mention of commercial operations

The collection of forest products was concentrated in the savannah, as much of the remaining forest is considered taboo, or *fady*; many respondents noted that they never go there. When asked how individuals depended on the forest, the overwhelming response was for harvesting trees for house construction or tools. While the majority of forests were "untouchable", each forest had portions, named *atiala velona*, where trees for construction could be requested through the local COBA. However, despite the consistent suggestion from informants that the remaining forest was considered taboo, it appeared that the forests were still being used for income either through charcoal production or selling timber in all three communities. In Ambodimadiro (AMB) it was evident that the savannah has been overexploited over the past 10 years, with many respondents commenting on the lack of trees available for any activity, including charcoal production. However, charcoal production was viewed as a major livelihood in the community in both wet and dry seasons, suggesting that the forest was often used for this purpose. When asked whether Beantely was increasing in size VAI14, a cultivator and charcoal producer, stated, "Increasing?! Increasing?! Everybody's using it for charcoal". Meanwhile, respondents in AND often mentioned the use of Beantely by members of the nearby village of Cap Diego, which lacks forests or trees in their savannah. Finally, in BAIE, it appears that instead of charcoal production, trees may be illegally cut from the forests for sale as timber. As VCI3 stated regarding individuals breaking forest rules, "…for those who struggle, they will take advantage to cut trees and sell them. Because they don't get enough help… you know, livelihoods in our area are so hard".

Due to the taboo nature of forest use in the region, it was difficult to discern exactly how dependent individuals were on forest resources. However, conversations with respondents revealed extreme livelihood limitations across all three communities, giving people no choice but to break local taboos and forest management rules. The following sections highlight the factors influencing livelihood options and subsequent resource use using the SLF (Fig 2).

[FIGURE 2]

## 3.2 Drivers of livelihood choices

### 3.2.1 Seasonality of rain and wind

The seasonality of rain was one of the most important factors driving livelihood choices across all three villages (Fig 3). Cultivation and cattle milking only occurred during the wet season (January-May), while fishing and charcoal production occurred year-round, but became the main livelihoods during the dry season as others became impossible. To maximize the returns from livelihoods during the wet season, it was essential to begin activities immediately upon the start of the rain, including planting crops (in particular rice) and milking cattle.

The dry season (June-December) was the time when it was difficult to find income, with few options available beyond fishing or producing charcoal. However fishing was limited between June and October due to strong easterly trade winds, the *varatraza*, and individuals lacking motorized boats were either unable to fish during this time or had greatly reduced catch. It was during this time that many noted having no other livelihood options beyond charcoal production.

Households in BAIE were particularly limited during this period, as fishing was the primary livelihood during both seasons and charcoal production for sale was prohibited.

[FIGURE 3]

### 3.2.2 Agricultural constraints

Rice was the most important crop for all respondents, but its high water demands made cultivation difficult in such a dry region. Due to the short rainy season, households needed to clear land in the savannah, dig irrigation canals and construct protective fences before the rain commenced. However, these activities were limited by a lack of tools (such as shovels, picks, ploughs) and/or cattle (for ploughing), as well as an overall lack of labour to collect wood for fence construction, a process that could take several weeks or months (Fig SI). Agriculture in BAIE was particularly limited due to local taboos preventing the use of ploughs.

The arrival and duration of the rainy season were highly unpredictable, affecting decisions over when to plant rice. Consequently, in AND and BAIE, households were hesitant to invest in such labour-intensive activities until rain started, which limited their production, while in AMB respondents prioritized planting rice but then risked a failed crop and lost labour if rain was not sufficient. Whereas some individuals avoided the risk completely and temporarily migrated to plant rice outside the region of Bobaomby. Due to these limitations, it was difficult for households to produce enough rice to last them the entire year, and they would be obliged to purchase rice for food in the months prior to harvest. Given the rising cost of rice, this left respondents unable to save income or invest it in livelihood improvements. As VBI4, a cattle

guard and cultivator, noted, "…I ensure that milk could help me save, but the biggest issue is food [rice]. So we have to use all of our income for surviving."

### 3.2.3 Declining fisheries catch

While the dependence on fishing varied within and between villages, respondents throughout commonly expressed concerns over declining catches over the past 10 years and the unreliable nature of fishing as a livelihood. This is concerning because fishing was an important livelihood for filling income gaps in the dry season in AMB and AND, and was the primary livelihood year-round in BAIE.

More people from both within and outside the study communities were fishing now relative to 10 years previously. Respondents commonly attributed declining catches to this increase in individuals fishing combined with a lack of materials allowing fishing offshore. This appears to have caused overexploitation of stocks within the bays. Furthermore, a lack of management was evident within both Antsiranana Bay and Nosy Hara MPA. While opening and closing periods and gear restrictions existed (Table 1), enforcement was lacking and rules were not commonly known, understood, respected (AMB, AND) or effective (BAIE): indeed, many respondents expressed concern that people from other communities fished illicitly in their bays. Respondents suggested that more people could be fishing due to increasing market prices, but also due to communities expanding their fishing grounds in response to a widespread trend of declining catches. Respondents in AND noted people from multiple communities across the Bay of Antsiranana fishing within their bay, including fishers from Antsiranana.

While declining fishing yields jeopardise income and food security in all communities, respondents nevertheless tended to prefer fishing over investing in agriculture because it involves less risk and can result in quicker income. When asked why he does not invest more in agriculture, VCI12 a fisher, cultivator and cattle owner, stated, "Ah, agriculture is hard because it only works during the rainy season, but fishing is good because you can fish all of the time…even if you don't get enough, one fish, two fish, it's okay."

### 3.3 Charcoal production as a safety net and the proposed PA

Overall, the livelihood choices across all three villages appeared to be driven by the need for cash to purchase food once subsistence supplies ran out: as all livelihoods were limited, respondents tended to regularly switch between activities to meet their needs. Fishing and charcoal production were important livelihoods to make up for shortfalls and generate cash, which was often used to purchase rice. However, decreased fish catches were causing people to turn increasingly to charcoal production. Furthermore, charcoal production appeared to be a more reliable livelihood relative to others. While it is more difficult to do in the wet season, respondents in AMB and AND produced it year-round. Charcoal represents guaranteed income, given the high market price in Antsiranana, and is more consistently available to communities than fishing or farming: therefore, despite being negatively perceived due to its dangerous and difficult nature, charcoal production was seen as an important safety net for many respondents. As VBI3, a community leader, explained, "…when people are hungry, they need to eat, they won't just stay and die. They will go to the sea, but there is nothing. So they will go to charcoal…"

When asked how establishment of the PA could affect livelihoods, most respondents only perceived a PA to affect their access to trees for house construction and did not mention restrictions on charcoal production. However the extent of charcoal production in AMB, combined with respondent comments on the lack of trees for charcoal in the savannah and the decreasing size of Beantely forest, suggest that households may rely on the forest for charcoal production more than they were comfortable revealing. While respondents in AND commonly noted the abundance of trees in their savannah and the increasing size of their forests following the implementation of COBA regulations, the situation in AMB could be used to predict what could occur in AND if charcoal production in the savannah is not sustainably managed in the future. As VBI10, a cultivator and cattle owner stated when asked what would happen in the community if trees in the savannah became overexploited, "I know that they will go [to the forest to produce charcoal]. This forest is not allowed, but since life is so hard, they will not cross their hands and die, they will go."

In BAIE, where there are prohibitions on charcoal production (Table 1), respondents appeared to be much more limited in their options for filling income gaps. Respondents spoke of more people turning to fishing or increasing their fishing efforts following the charcoal prohibition, however, as marine productivity decreases, this appears to be insufficient. While historically households in BAIE rarely cultivated crops, some households are now turning more to agriculture in an attempt to fill gaps despite local taboos restricting the use of ploughs. There was also evidence that people may be selling forest timber, and thus continuing to use the forest as a safety net even without producing charcoal. When noting that individuals do not always respect local forest management rules, COBA leader VCI3, stated,

> "Imagine now [the price of] rice is increasing every day and the more the price of rice is increasing, the desire of people to cut trees will increase too. Because maybe one tree would buy food before, but now it wouldn't, so they will add more trees."

Additionally, there was an overall displeasure towards the prohibition on charcoal production, with some individuals expressing the desire and readiness to produce charcoal if their livelihoods do not improve.

Overall, it appeared that respondents across all communities did not view charcoal as a preferred livelihood and many relied on it primarily for income once their food reserves had run out; however, some respondents indicated that income from charcoal was also used for daily needs, such as soap, sugar or clothes, and for longer-term investments such as education for their children, purchasing cattle, buying tools or sending money to family elsewhere. Additionally, there was evidence that some individuals in AMB produce charcoal as part of a larger-scale illicit trade influenced by more powerful external actors. As a community leader, VAI17, stated, "It is also too hard, some people are behind this business….people produce 250-600 bags, that's not for food": in addition, authorities have been observed allowing producers without permits to pass through checkpoints in exchange for bags of charcoal. Migration of families from southern Madagascar was noted as a common trend in this village, with households often turning to charcoal production on arrival and encouraging the migration of other family members. The greater accessibility (and market integration) of AMB compared to the other villages, combined with a lack of trees for charcoal in the savannah, has led to overexploitation of forest resources near this village.

Respondents across all three communities were aware of the environmental consequences of charcoal production in their communities; however, it was clear that it will likely continue to be an important livelihood as long as demand remains high and other livelihoods remain too risky or unproductive. If enforcement of charcoal production in AMB does not improve, charcoal production in the savannah is not managed sustainably in AND, and alternative livelihoods are not supported in BAIE, increased forest exploitation in the region is highly likely. This will negatively affect the long-term sustainability of Bobaomby PA. Due to the difficulties faced in finding food, many respondents perceived agriculture as the livelihood requiring the most support to help reduce pressures on the forests. As VAI3, a community elder, stated, "…If everyone is doing well in agriculture, no one will go to Beantely [the forest]. If more people are planting, Beantely will be free. No one will go and touch it. But the problem nowadays, is agriculture is worth nothing." However, other respondents also stressed the importance of the sustainable management of all aspects of the landscape, including the sea and savannah. When asked what should be done to protect the forests, VBI4, a fisher, cattle guard and cultivator explained,

> "Well, I think the actors who are planning to manage it, shouldn't focus only on the forest, but they need to protect everything…Because if the sea is not protected too, some people get help from there. They wouldn't just cross their hands and die, but they will go more and more to the savannah for charcoal, and if the savannah disappeared, they would go further [to the forest]. And we know that the savannah is not enough for charcoal, for wood for cooking, for agriculture and for cattle. So I think they really need to focus also on the sea."

## 4. DISCUSSION

This study revealed multiple factors limiting livelihood productivity in communities surrounding the proposed Bobaomby PA, leading to overexploitation of both marine and forest resources and ultimately weakening the resource-bases that livelihoods depend on. While the existing institutions of local taboos and COBA management could contribute to forest protection and provide a foundation for further management through PA establishment, the high vulnerability and constrained livelihoods of local communities mean that forests will likely remain an attractive resource to exploit. Given that local livelihoods rely on all components of the landscape, from the savannah to the mangroves, seas and forests, the PA managers will therefore have to address the sustainability of all livelihood activities if they are to achieve the long-term conservation of forests in the PA. Our research provides a number of insights into how they may do so.

### 4.1 Resource use in an environment of high vulnerability and risk

We found charcoal production to be the most significant livelihood related to forest use, as well as being critically important for cash income to purchase food or other items in times of need. Charcoal production is an important livelihood amongst rural communities across Africa and Madagascar (Ackermann 2003; Minten et al. 2013; Zulu and Richardson 2013; Gardner et al. 2016a), offering a source of income during the agricultural off-season (Kalaba et al. 2013; Zulu and Richardson 2013; Ndegwa et al. 2016; Mulenga et al. 2017; Smith et al. 2017), and providing a safety net in case of shocks such as crop failures (Gardner et al. 2016a; Jones et al. 2016; Ndegwa et al. 2016; Smith et al. 2017). Declining agricultural productivity has thus led to

417 increased charcoal production in southwestern Madagascar (Casse et al. 2004; Gardner et al.
418 2016a) and in other areas of Africa (Khundi et al. 2011; Mulenga et al. 2017).

419 Many respondents turned to charcoal production due to insufficient agricultural yields, but
420 agriculture is a high risk livelihood because of unpredictable rainfall, risks from cattle grazing,
421 and the high labour investments required. These risks appeared to limit or prevent investments in
422 agriculture, further increasing dependence on the safety net of charcoal production. Fishing was
423 also highly variable in its returns, but is less risky because initial investments are lower, the
424 return on investment is rapidly known, and there is high demand for fisheries products in
425 Antsiranana. However, given the trend of decreased catch over the past decade, the risks
426 associated with fishing are increasing.

427 While charcoal production also carries risks, including health risks, and (for producers lacking
428 permits) the risk of confiscation (Smith et al. 2017), charcoal can be produced year-round and,
429 being one of the most common domestic fuel sources in urban areas, enjoys relatively continuous
430 demand and stable prices (Mwampamba et al. 2013; Zulu and Richardson 2013). Despite being
431 dangerous and labour-intensive, charcoal production requires little to no capital investment or
432 technical know-how, and is therefore a livelihood with few barriers to entry (Arnold et al. 2006;
433 Zulu and Richardson 2013). As such, it is a relatively low risk livelihood compared to those
434 requiring high initial investments (i.e. farming) or those vulnerable to unpredictable or variable
435 returns (including both fishing and farming). As elsewhere in rural Madagascar, the highly
436 unpredictable environment and the subsequent feelings of vulnerability and risk aversion
437 amongst respondents appeared to be a major influence in livelihood decision-making (Neudert et
438 al. 2015; Tucker et al. 2015; Penot et al. 2018).

Charcoal production can provide quick income in times of need, but also to buy expensive assets, invest in other livelihoods, or to pay for large expenses (Zulu and Richardson 2013; Jones et al. 2016; Smith et al. 2017). We found charcoal production to be attractive as a flexible income source that can be used for a variety of purposes (Smith et al. 2017). Therefore, we expect it will continue being a significant livelihood in the study area even if other livelihoods are supported and significantly improve. This could be a concern both for the success of the proposed PA and the sustainability of local livelihoods, because charcoal production contributes to forest degradation and localized deforestation across the tropics, thus undermining its own resource base (Chidumayo and Gumbo 2013; Zulu and Richardson 2013). In Madagascar, it constitutes a significant threat to biodiversity in and around dry forests (Ackermann 2003; Ramarolanonana et al. 2017), including to the integrity of PAs (Gardner et al. 2016b). In Bobaomby, evidence that charcoal production is threatening the ecological integrity of the study site includes the disappearance of trees in the savannah of AMB, and the decreasing size of Beantely forest which was regularly reported by respondents. While the savannah in AND currently retains sufficient trees for production, the overexploitation of savannah trees and subsequent forest-use may occur there too in the near future, if other livelihoods continue to be limited. It is also probable that, without future change in livelihoods, charcoal production is likely to recur in BAIE.

The unsustainable nature of charcoal production threatens both the forests of Bobaomby PA and the future incomes of those who rely on it. Therefore, management should focus on the development of sustainable charcoal production systems in the savannah (for example through plantations of fast growing trees), alongside the enforcement of existing rules. However, the maturation of alternative wood sources will take several years, so strict exclusion from forest use

for charcoal production will likely not be a feasible or appropriate PA management strategy at the onset due to the costs this would impose on local communities.

### 4.2 The future of livelihoods in a dry environment

Livelihoods in Madagascar's arid environments are highly limited and, given the increasing unpredictability of rainfall, risky and vulnerable (Ackermann 2003; Harvey et al. 2014; Waeber et al. 2015; Hänke and Barkmann 2017). In the south and west of the country, which also have a short and unpredictable rainy season, agriculture and cattle rearing are also the main livelihoods: however, in these regions the principal crops are maize, manioc and/or peanuts, rather than rice (Harvey et al. 2014; Waeber et al. 2015). While rice cultivation was attempted by many respondents in our study, households in AND and BAIE adapted to the dry environment by only planting rice if rain started, and by prioritizing planting maize which does better in drier conditions. With predictions of increased temperature and decreased rainfall as a result of climate change, agricultural yields (particularly of rice) will likely decline in the region without interventions (Zougmoré et al. 2018).

As throughout the dry regions of Madagascar, cattle rearing was an important livelihood for all study communities (Casse et al. 2004; Ratovomanana et al. 2013; Waeber et al. 2015; Hänke and Barkmann 2017). However, both the number of people rearing cattle and the total number of cattle reared has been in decline due to decreased rainfall and increased cattle mortality. While respondents often noted cattle rearing as the livelihood with the greatest earning potential, current trends and climate change projections suggest that it will become increasingly difficult in the future (Zougmoré et al. 2018). This will not only reduce revenues from milk production, but

could also affect the capacity of households to respond to shocks, as cattle serve as a store of wealth that can be sold in times of need. As a result, households may increasingly turn to other livelihoods, such as charcoal production, to fill income gaps (as has been observed amongst herders in Tanzania, Butz et al. 2013).

### 4.3 Fishing as a livelihood strategy

Fishing played an important role in the livelihoods of each community, however it was becoming less reliable due to decreased catches. This reflects trends of declining fisheries production both in northern Madagascar (Browne et al. 2007; Narozanski et al. 2011; Robinson and Sauer 2013) and nationwide (Laroche et al. 1997; Cripps and Gardner 2016;), as a result of overexploitation and the use of destructive methods. While overfishing may be the result of local demographic growth, it is also influenced by limitations in other livelihoods which see people increasingly turn to fishing (Narozanski et al. 2011).

Declining catches drive fishers to extend their fishing grounds (Browne et al. 2007), which may explain the increase in fishers from neighbouring communities reported by our respondents. They may also drive fishers to use more destructive methods, such as seine nets, in an attempt to maintain catches, which can ultimately create a poverty trap as the natural capital continues to degrade (Harris 2011). While rules concerning seasonal fisheries closures and gear restrictions exist across the study region, they appear to be either unenforced or insufficient to arrest fisheries declines.

503 Fishing is a lower risk livelihood than agriculture in our study region, a perception also held by
504 communities elsewhere in Madagascar (Tucker et al. 2015). Therefore, we expect that fishing
505 will remain an important livelihood in the region; however, if catches continue to decrease,
506 communities will need to turn elsewhere, including the savannah and forests, to make up for
507 income shortfalls. Decreased viability of fishing has led to increased bushmeat hunting in West
508 Africa (Brashares et al. 2004) and increased charcoal production in Madagascar (Laroche et al.
509 1997; Gardner et al. 2016a). This was already apparent in our study, with charcoal often being
510 used to fill income gaps that fishing could not complete. Overall, the limitations of other
511 livelihoods, compounded by insufficient management of marine resources, has led to
512 overexploitation and the unsustainable nature of fishing as a livelihood. With further declines in
513 catch potential projected under climate change (Cheung et al. 2010), the ability of the ocean to
514 sustain local livelihoods is under threat.

515

516 **4.4 Implications for PA management**

517 While forests are the principal conservation target of the PA, management interventions will
518 need to focus equally on the savannah, coasts and marine environment in order to promote
519 sustainable livelihoods and thus reduce pressures on forest resources in the long term (Fig 4).
520 Local taboos on forest-use may be beneficial to long-term PA management, but are not robust in
521 the face of hunger and destitution; thus, they will only be respected if existing and alternative
522 livelihoods receive support, and the availability of resources within other parts of the landscape
523 is enhanced.

Agriculture requires urgent support because agricultural limitations appeared to be the most significant driver of charcoal production. While respondents suggested that the provision of seeds and tools for clearing land within the savannah would be beneficial, the risks associated with agriculture need to be addressed first to encourage greater investment in this livelihood. First, more efficient and less labour-intensive methods and materials (such as barbed wire, as suggested by respondents) are required for building fences to protect crops from cattle, particularly as this would also reduce pressure on wood resources. Risks associated with unpredictable rain also need to be addressed, for example through crop insurance schemes or the dissemination of climate information (Zougmoré et al. 2018), and/or the provision of seeds for rice varieties requiring less water (Harvey et al. 2014; this study).. Managers should also stimulate a transition away from rice production to crops that grow better in drier conditions and are perceived as lower risk by cultivators, such as maize, pumpkins or beans (Tucker et al. 2015; this study). However, a shift to cash cropping should be accompanied by investments, such as soil and fertility management, to ensure that cultivation is carried out in permanent fields rather than through shifting cultivation, which has been a major driver of deforestation in other dry regions (e.g. Casse et al. 2004; Scales 2014). Additionally, respondents suggested that water management should be improved by building rainwater capture and small-scale irrigation infrastructure, as well as wells and water points for cattle (Desbureaux and Damania 2018).. While some Malagasy farming communities are adapting their practices to climate change, farmers often lack the technical support to take up new methods, therefore training and disseminating information on techniques and best practices will be essential (Harvey et al. 2014).

Given that charcoal will likely remain the principal cooking fuel in urban areas for the foreseeable future (Mwampamba et al. 2013), investments are also required to reduce the

impacts of its production. Repondents suggested that plantations of fast-growing trees should be established in the savannah (particularly in AMB), and that existing charcoal improvement projects in the region (such as GTZ's 'green charcoal' program) should be expanded. Plantations should use species with a high growth rate, the ability to grow in dry conditions, and potential for improving soil fertility, as well as the potential for use as fencing materials, firewood, and fodder for cattle (Partey et al. 2018). However, the potential for species to become invasive should also be considered (McConnell et al. 2015). Furthermore, as interventions aim to expand agriculture and plantations in the savannah, the competing requirement for cattle grazing land will need to be considered because conflicts over land could lead to forest encroachment in the long term (Ratovomanana et al. 2013).

We recognize that the sensitive nature of forest use and related taboos may have prevented respondents from being completely honest in their answers related to charcoal production and other forest uses. However, we suspect that this only underplays the importance of forest use to local livelihoods. While charcoal production represents the greatest direct threat to the proposed PA, the experience of charcoal prohibitions in BAIE, which stimulated an increase in fishing effort and exacerbated overfishing, should caution managers about potential unintended consequences if more stringent rules on charcoal production are implemented in AMB and/or AND.

[FIGURE 4]

While the issue of decreased fishing catch is more difficult to address for managers of a terrestrial PA, respondents suggested that strengthening (AND and BAIE) or creating (AMB) institutions for managing marine resources and enforcing gear-based rules would help reduce

overexploitation. However, further collaboration with MEDD and Madagascar National Parks is required to improve overall marine management and enforcement of rules within Antsiranana Bay and Nosy Hara MPA. Meanwhile, it will be imperative to decrease fishing pressure locally by providing alternative livelihoods to those who rely on fishing (Newton et al. 2007), while also implementing sexual health and family planning services to reduce pressures in the long-term (Harris et al. 2012; Singleton et al. 2019). Aquaculture, for example of Holothuria (sea cucumbers) or algae, could also be considered as an alternative income source (Robinson and Pascal 2009). Such interventions are particularly important for BAIE where the safety net of charcoal production is not legally available.

Implementing the above recommendations will be challenging given the inaccessibility of the villages, their relative state of impoverishment, and the difficulties securing funding for new PAs in Madagascar (Virah-Sawmy et al. 2014; Gardner et al., 2018). Nevertheless, this research demonstrates the value of ascertaining and understanding the livelihood needs of local communities so they can be integrated into PA management. While agricultural support has potential to reduce dependence on charcoal production, the interconnectivity between different livelihood activities highlights the importance of a landscape approach to management, in which the livelihood trade-offs faced by all stakeholders are carefully considered (Sayer et al. 2013). It will also be necessary to consider lessons learned from other PAs in Madagascar (e.g. Rabesahala et al. 1995), however the valuable experiences of PA managers are rarely published in the peer-reviewed literature.

Finally, it should be cautioned that any PA investments in local communities will alter the dynamics of the socioecological system, and thus require careful management. For example, potential improvements in income arising through investments in livelihoods could be invested

592 in further exploitation of resources (Scales et al. 2018): therefore, development interventions
593 must be implemented alongside improved enforcement of existing rules (Gardner et al. 2013).
594 Further, the needs and perceptions of local communities may change over time, and may not
595 always align with the aims and goals of the PA promoters (Keller 2008). Managers should
596 therefore adopt an adaptive management approach informed by participatory decisionmaking and
597 socioeconomic monitoring, to ensure that management is able to rapidly respond to both
598 emerging threats and the changing needs of resident communities (Gardner et al. 2016a).

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602

| Livelihood | Perceived support required | Number of respondents |
|---|---|---|
| **Agriculture** | Water | 21 |
| | Tools | 19 |
| | Strong fences | 12 |
| | Rules on zebu | 7 |
| | Seeds | 5 |
| | Fertilizer (Soil) | 1 |
| | Herbicide | 1 |
| **Fishing** | Tools | 17 |
| | Enforcement of rules | 6 |
| **Farming zebu** | Water | 6 |
| **Farming poultry** | Money to invest in chicks | 8 |
| | Food | 8 |
| | Poultry house | 3 |
| | Vaccinations | 3 |
| | Water | 2 |
| | Training | 1 |

603

**Table 7.** The different agricultural crops discussed during interviews and attitudes towards planting them

604

605

| Crop | Attitude | Reasoning |
|---|---|---|
| Rice | Positive | Culturally important and is included in every meal; high market price |
| Maize | Mostly positive, some negative | Grows well in drier conditions and without consistent weeding and could be used to feed poultry, but zebu like to eat it |
| Cassava | Mostly positive, some negative | Grows well in drier conditions but wild pigs like to eat it |
| Pumpkins | Positive | Grows well in drier conditions |
| Squash | Positive | Grows well in drier conditions |
| Tomatoes | Positive | Grows well in drier conditions |
| Banana | Positive | Grows well in drier conditions and has high market price |
| Peanuts | Mostly positive, some negative | Grows well in drier conditions but mixed opinions on whether or not a plough is needed for planting |
| Cucumber | Positive | Grows well in drier conditions |
| Sweet potatoes | Positive | Grows well in drier conditions |
| Other garden vegetables | Mostly negative, some positive | Requires a lot of water but could be planted only during rainy season |

## 5. CONCLUSION

The livelihoods of rural communities around Bobaomby are highly limited by the lack of natural, physical, human, financial and social assets, which has led to overexploitation of natural resources and overall feelings of risk and vulnerability. Without support and investments in livelihood-based interventions, the viability of the forests, and thus the PA established to conserve them, will be unlikely in the long term. Given that many PAs in Madagascar and worldwide are established in contexts where local communities depend on natural resources from

within the protected area for their subsistence or income (Pringle 2017; Gardner et al. 2018; Horning 2018), this is likely to be a widespread situation. Nevertheless, many PAs around the world continue to be ineffectively managed and fail to achieve desired conservation or social outcomes (Geldmann et al. 2013; Oldekop et al. 2016); highlighting the need for further research to understand how needs of local communities and the objectives of PA managers can be aligned across a range of ecological and socioeconomic contexts.

While local-level interventions should be a priority, macro-scale issues such as the demand for charcoal and population growth will also need to be addressed to promote sustainability of both the proposed PA and forest ecosystems across the country (Mulenga et al. 2017). This research has highlighted the value of understanding livelihoods to inform PA management and enable the development of interventions designed to conserve forests while supporting the livelihoods of impoverished local communities. In particular, while conservation efforts in Madagascar have mainly focused on terrestrial landscapes (Harris 2011), our results illustrate the complex interaction between marine and terrestrial resource use in coastal regions, and highlight the need for marine management considerations within coastal terrestrial PA management planning.

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## LIST OF FIGURES, TABLES & SUPPLEMENTARY MATERIAL

857 **TABLES**

858 Table 1 Characteristics of the three study villages, including the hamlets sampled, population, number of households and varying

859 details influencing resource use

| | Ambodimadiro (AMB) | Andohazompona (AND) | Baie de Courier (BAIE) |
|---|---|---|---|
| **Municipality** | Antsahampano | Andranovondronina | Andranovondronina |
| **Hamlets sampled** | Ambodimadiro<br>Andilamavo<br>Andranomamy<br>Morafeno | N/A-not divided into hamlets | Andramahimba<br>Madiro Kitamby<br>Ambaro<br>Illomotro<br>Antsatrabe |
| **Population** | 647 | 147 | 187 |
| **# households** | 98 | 37 | 42 |
| **Distance to Antsiranana (km)** | 25 | 30 | 50 |
| **Local bush taxi access** | Yes along RN29, during both wet and dry season | Yes along unmaintained road, only during the dry season | No, sectors of Andramahimba, Madiro Kitamby, Ambaro and Illomotro only accessible on unmaintained road via private vehicle during dry season at low tide |
| **Forest restrictions** | COBA Active since 2015, restricts charcoal production to areas below a set delimitation within Beantely forest, for sale with permit; permits needed to harvest trees within forest for construction | COBA Active since 2007, restricts charcoal production to savannah using specific tree species, for sale with permit; permits needed to harvest trees within forest for construction | COBA Active since 2007, restricts charcoal production to savannah for personal consumption only (prohibitions in place since 2015); permits needed to harvest trees within forest for construction |
| **Fisheries restrictions** | Opening and closing periods for crab, octopus and shrimp and bans on use of small mesh-size nets across Antsiranana | Opening and closing periods for crab, octopus and shrimp and bans on use of small mesh-size nets across | CLP Active since 2010, applies opening and closing periods for crab, octopus and shrimp and bans use of |

| | | | |
|---|---|---|---|
| | Bay, however no local CLP | Antsiranana Bay, however inactive CLP without official status | small mesh-size nets<br>Nosy Hara MPA rules ban fishing close to the islands included within its boundaries |
| **Local taboos related to resource use** | Taboo to:<br>-Kill animals in the forest, including lemurs and reptiles<br>-Sell tenrecs<br>-Eat wild pig<br>-Work the land on Tuesday or Thursday | Taboo to:<br>-Kill animals in the forest, including lemurs and reptiles<br>-Sell tenrecs<br>-Eat wild pig<br>-Work the land on Tuesday or Thursday | Taboo to:<br>-Kill animals in the forest, including lemurs and reptiles<br>-Sell tenrecs<br>-Eat wild pig<br>-Work the land on Tuesday or Thursday<br>-Sell milk<br>-Work the land with a plough |
| **Resource areas used** | Surrounding wooded savannah, Beantely forest and the bay of Cul-de-Sac Gallois and associated mangroves/mudflats.<br>Many restricted to fishing along and within bays, due to eastern location within Antsiranana Bay. Open sea less accessible relative to communities on western shore. | Surrounding wooded savannah, Beantely, Ankarandoha, Analabe and Sacred forests and the bay of Andovobatofotsy and associated mangroves/mudflats.<br>Many restricted to fishing along and within bays, due to eastern location within Antsiranana Bay. Bays easily accessed by individuals from Antsiranana. Open sea less accessible relative to communities on western shore. | Surrounding wooded savannah, Beantely, Windsor Castle and Analabe forests and multiple bays along west coast, associated mangroves/mudflats and Nosy Hara MPA waters.<br>Less sheltered bays relative to AMB and AND due to western location along Nosy Hara MPA More easily accessed open sea relative to AMB and AND. |

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862 **Supplementary Online Material**

863 **Table SI**: Details of livelihood activities present across the three study villages

| | Ambodimadiro (AMB) | | Andohazompona (AND) | | Baie de Courier (BAIE) | |
|---|---|---|---|---|---|---|
| **Main livelihoods** | **Wet season**<br>Raising/milking cattle<br>Agriculture-permanent and shifting cultivation<br>Some fishing<br>Some charcoal | **Dry season**<br>Charcoal<br>Some fishing | **Wet season**<br>Raising/milking cattle<br>Agriculture-permanent and shifting cultivation<br>Some fishing<br>Some charcoal | **Dry season**<br>Charcoal<br>Some fishing | **Wet season**<br>Fishing<br>Raising cattle<br>Agriculture-permanent and shifting cultivation | **Dry season**<br>Fishing |
| Agriculture | **Main**<br>irrigated rice<br>maize | **Other**<br>beans<br>cassava<br>pumpkin<br>sweet potato<br>cucumber<br>tomatoes | **Main**<br>maize<br>sometimes irrigated rice | **Other**<br>cassava<br>cucumber<br>pumpkin<br>tomatoes<br>squash<br>peanuts<br>bananas | **Main**<br>maize<br>sometimes irrigated rice | **Other**<br>cucumber<br>pumpkin<br>squash<br>tomatoes<br>cassava<br>peanuts |
| | **Use**<br>Mostly for consumption, if surplus sold in local area or Antsiranana | **Use**<br>Mostly for consumption, if surplus sold in local area or Antsiranana | **Use**<br>Mostly for consumption, if surplus sold in local area or Antsiranana | **Use**<br>Mostly for consumption, if surplus sold in local area or Antsiranana | **Use**<br>Mostly for consumption, if surplus sold in local area or Antsiranana | **Use**<br>Mostly for consumption, if surplus sold in local area or Antsiranana |
| Livestock rearing | **Main**<br>cattle | **Other**<br>chickens<br>ducks | **Main**<br>cattle | **Other**<br>chickens<br>ducks | **Main**<br>cattle | **Other**<br>chickens<br>ducks<br>goats |

| | | | | | | |
|---|---|---|---|---|---|---|
| | **Use**<br>Raised for sale/insurance and/or milking for income<br>Milk sold to local collectors | **Use**<br>Raised for sale in local area or personal consumption | **Use**<br>Raised for sale/insurance and/or milking for income<br>Milk sold to local collectors | **Use**<br>Raised for sale in local area or personal consumption | **Use**<br>Raised for sale/insurance and/or milking for personal consumption only | **Use**<br>Raised for sale in local area or personal consumption |
| Fishing | **Main**<br>fish<br>shrimp<br>*patsa* | **Other**<br>crabs | **Main**<br>fish<br>shrimp<br>*patsa* | **Other**<br>sea cucumber<br>octopus | **Main**<br>fish | **Other**<br>crab<br>octopus |
| | **Use**<br>For sale or personal consumption<br>Sold to local collectors, or personally sold in local area or transported for sale in Antsiranana | **Use**<br>Sometimes for sale within local area or Antsiranana, dependent on quantity. Mostly for personal consumption. | **Use**<br>For sale or personal consumption<br>Sold to local collectors, or personally sold in local area or transported for sale in Antsiranana | **Use**<br>Sometimes for sale within local area or Antsiranana, dependent on quantity. Mostly for personal consumption. | **Use**<br>For sale or personal consumption<br>Sold to local collectors, or personally sold in local area or transported for sale in Antsiranana | **Use**<br>Sometimes for sale within local area or Antsiranana, dependent on quantity. Mostly for personal consumption. |
| Charcoal production | Produced during both wet and dry seasons, mostly for income, but some for personal consumption<br>Sold to collectors or personally transported for sale in Antsiranana | | Produced during both wet and dry seasons, mostly for income, but some for personal consumption<br>Sold to collectors or personally transported for sale in Antsiranana | | Some produced from trees cleared for agriculture, but only for personal consumption | |
| Other | Only fishing year-round<br>Charcoal collector<br>Marine product collector | | Only fishing year-round<br>Shopkeepers<br>Carpenter<br>Charcoal collector<br>Milk collector | | Producer of mats and baskets<br>Seamstress<br>Shopkeeper<br>Marine product collector | |