Forest ecosystem services derived by smallholder farmers in northwestern Madagascar: Storm hazard mitigation and participation in forest management

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A B S T R A C T

Tropical dry deciduous forests provide numerous ecosystem services yet their contribution to agricultural production remains underexplored. We address this research gap by quantifying the broader suite of ecosystem services that support small holder farmers and identifying farmers' knowledge of storm hazard reduction benefits provided by forest fragments in Madagascar. We survey 240 households and interview eight key informants to identify household and community responses in two communities with contrasting forest cover trajectories. Using multivariate statistics, results show a heavy dependence on forests for food and raw materials and a majority of the respondents holding a positive view of hazard mitigation services provided by forest fragments. Education levels, earning an income from forest based tourism and honey production are the only predictors of participation in forest management. Positive view of the hazard reduction benefits derived from forests could be due to external influences or personal observations, and together with barriers to participation in forest management need to be further investigated to better link forest management to reduced hazards risks. These findings are significant for forest management policy, as local knowledge and rationale for decisions are instrumental in the success of decentralized forest management and maintenance of vital forest benefits to farmers.

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1. Introduction

Tropical dry deciduous forests, one of the most threatened biomes on the planet, hold a high density of mammalian biomass and provide essential ecosystem services to people (Lerdau et al., 1991; Maass et al., 2005). These forests provide water regulation and pollination services as well as food, timber, water for irrigation and non-timber forest products (Maass et al., 2005). Ecosystem services, defined as the benefits people derive from nature (MA, 2005), provide an anthropocentric motivation for sustaining nature to support human needs and society (Fisher et al., 2014). Provisioning services such as timber, food and non-timber forest products that can be used directly by people are more easily linked to human needs (Daily et al., 1997; Barbier et al., 2010; Wunder et al., 2014). However, forests, wetlands and coastal habitats also provide several regulating services that aid in disaster risk reduction by decreasing the exposure of communities to hazards such as floods and storm surge (Sudmeier-Rieux et al., 2006; Brauman et al., 2007; Laurance, 2007; Martin and Watson, 2016). While much attention has been paid to the role of forests in supporting rural livelihoods through provisioning services, less work has been done on

assessing the importance of the hazard reduction functions of forests (Howe et al., 2014). In this paper we address this research gap by providing a detailed case study of the hazard mitigation services generated and valued by smallholder farmers in a tropical deciduous forest mosaic in northwest Madagascar.

Land cover change, particularly deforestation, is hypothesized to increase flood risk (Bradshaw et al., 2007) and is seen as a primary driver of soil erosion and consequent siltation of irrigation channels and agricultural fields (Bakoariniaina et al., 2006; Minten and Randrianarisoa, 2012). Inland forests have been argued to reduce the frequency and magnitude of floods, and there is some consensus that compared with other land uses, tropical forests reduce peak flows from small catchments during small to medium rainfall events (Bruijnzeel, 2004; Alila et al., 2009; Tan-Soo et al., 2014). In the bioengineering literature, forests, especially in mountainous areas, are considered to provide protection for exposed communities from rockfalls, debris flows, erosion, floods and shallow landslides (Brang et al., 2001; Dorren et al., 2004; Alila et al., 2009). Flood risk is also mediated by human decisions about land use and land cover change including the type and location of farms, urban and semi-urban areas, plantations, and industrial areas (Wisner et al., 2004; Wheater and Evans, 2009). Thus the exact relationship between forest cover and changes in flood frequency and magnitude and consequent impacts on people varies

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between sites, with both biophysical and social elements influencing this relationship (Bruijnzeel, 2004; Blöschl et al., 2007).

Two of the approaches commonly relied upon in the biophysical assessment of the effects of forest loss on hydrological processes are paired catchment studies and process based modelling (Wilk et al., 2001; Bruijnzeel, 2004; DeFries and Eshleman, 2004; Krishnaswamy et al., 2012; Kuraś et al., 2012). Despite a lack of application in the developing world, studies using these approaches have yielded some consensus on the role of forest cover in reducing flood hazards and different forms of erosion and sediment yield in some situations. For instance, it is understood that total annual water yield (flooding) increases with the percentage of forest biomass lost after conversion and that dry season flow can decrease with time as groundwater replenishment decreases after a number of years (Bruijnzeel, 2004; Kuraś et al., 2012). In general these findings are site specific, and remain difficult to extrapolate to other areas or larger scales as there is too much variation in findings (Bruijnzeel, 2004; DeFries and Eshleman, 2004). Thus, as Van Dijk et al. (2009) and Calder and Aylward (2006) state, there are no simple causal relationships between forest cover change and changes in floods or erosional impacts.

Ecosystem services generated by seasonally dry tropical deciduous forests (TDF) are some of the most understudied set of socio-ecological interactions (Maass et al., 2005) particularly in the developing world. Seasonally dry forests have seen widespread transformation by people and are considered as the most threatened of tropical forests (Miles et al., 2006; Becknell et al., 2012). Madagascar's dry deciduous forests form one of 200 ecoregions identified as ecosystems with high global conservation value that are also facing critical threats (Olson and Dinerstein, 1998). Threats to these forests differ in different regions, with fires and conversion for agriculture the most important direct threats in Africa (Geist and Lambin, 2002; Lambin et al., 2003; Miles et al., 2006). We argue that if the role of forests in reducing excess sedimentation and debris flows and floods in rural areas is to be better understood, a more focused investigation of the environmental knowledge base of local communities in forest frontier regions is needed. Unlike the use of hydrological models or paired catchment studies, we employ a local knowledge and perceptions' approach to assess agricultural risk reduction benefits derived from regulating services provided by forests as it is these perceptions that will shape local land use decisions and the effectiveness of forest management policies. In this paper, using an ecosystem services' lens, we employ household surveys in seven villages in Madagascar as a means to identify local benefits derived from seasonally dry TDFs landscapes, and how hazard mitigation is perceived as an ecosystem benefit valued by farmers in forest frontier areas (Fig.1). We hypothesize that:

1) Farmers in seasonally dry forest mosaics derive livelihood benefits from forest patches, including hazard mitigation services.
2) Farmers' understanding of the forest-hydrological cycle linkages is associated positively with less exploitative uses of forests and with perceiving the hazard mitigation benefits of forests, especially with flood regulation.
3) Deriving forest use benefits and perceiving hazard mitigation benefits of forests motivates participation in community forest management groups.

We first describe the study area, methods of data collection and analyses performed, then focus on answering three research questions, which address the hypotheses above:

- What are the forest ecosystem services, including hazard mitigation services, and benefits to livelihoods derived by small-holder farmers in seasonally dry deciduous forest zones?
- How do farmers understand the relationship between forest cover and water regulation, and how is this associated with their attitude towards forest ecosystem benefits including hazard mitigation services?
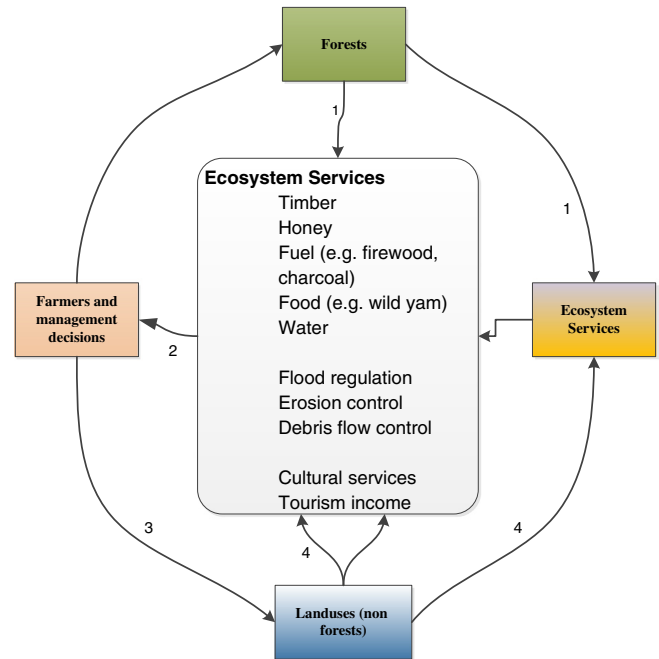

Fig. 1. The pathways of ES flows from forests (1) to farmers include the use of raw materials, e.g. timber, honey production, fuelwood, food, tourism income and recognition of regulatory services such as flood and erosion control (2). Such uses and benefits have consequent land use impacts (3) which feed back into ES flows and benefits to farm households and influence forest management decisions (4). Our research questions focus on the uses and perceived regulatory services derived by farmers and linkages to forest management decisions.

- What is the relationship between the acknowledged livelihood benefits of ecosystem services and the willingness of people to actively protect forests (using a proxy variable of engaging in forest management group activities)?

We then present the results on the frequency of use of various forest ecosystem services, whether farmers' acknowledge flood and sedimentation hazard reduction benefits of forest fragments found locally across the study area, and how these uses and attitudes translate into valuation of forests through participation in forest management activities for the site with existing forest management groups. We conclude by discussing the implications of these findings for different aspects of forest management policies, including decentralized governance of forest resources, and implications for linking forest management to agricultural hazard reduction policies and livelihood benefits.

2. Study area

We study this problem in the Boeny region of northwestern Madagascar, which experiences a strong seasonal variation in precipitation that influences all aspects of the agropastoral rural lifestyle. The yearly average rainfall is 1700 mm, with a distinct rainy season during November to March (Funk et al., 2015). The region is characterized by small-scale farming and a population dependent upon the surrounding landscape for everyday needs. In addition to farming, land cover includes seasonally dry broadleaf deciduous forest patches, lakes, raphia wetland remnants, and grasslands dominated by the endemic palm, known locally as satrana. Additionally, fruit trees such as the jackfruit tree and papaya are found abundantly in areas of human habitation, with much of the produce being transported to the city of Mahajanga (nearest urban center). Rice farming dominates agricultural production, which can be typically characterized as small-holder subsistence, primarily rain-fed, farming. Maize and cassava form the secondary
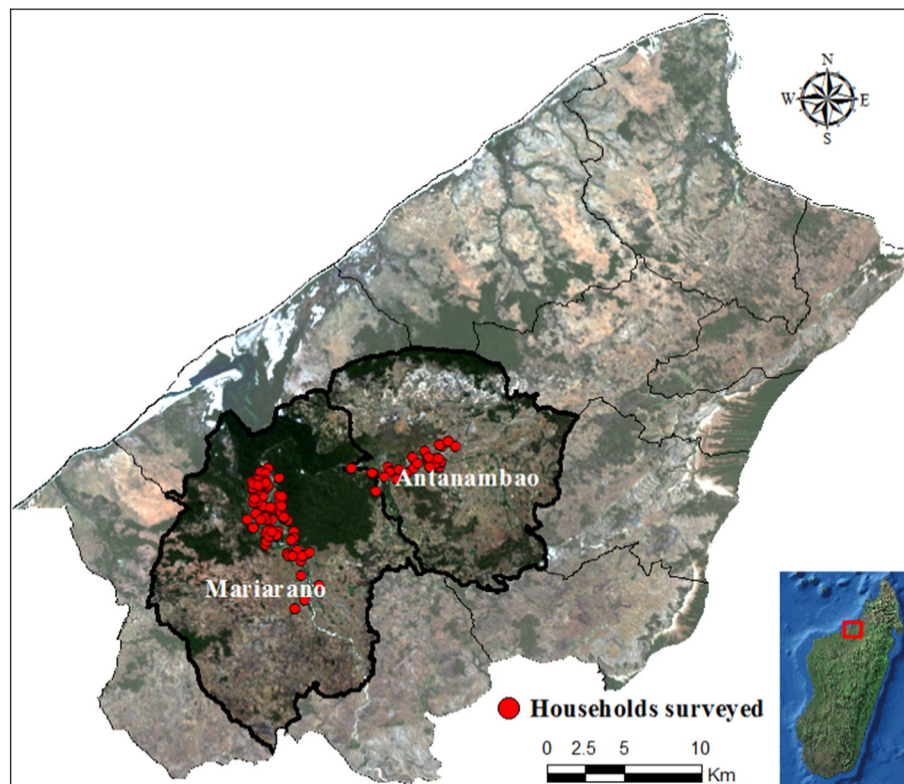
Fig. 2. Map showing the location of the study area within northwestern Madagascar. The red dots indicate various sites at which households were surveyed, the bold boundaries encompass the *fokontany* of Antanambao and Mariarano, within the boundary of Mariarano commune. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
Source: Landsat-TM 5, Year: 2009.

staples in the region. Cattle ownership is an important aspect of the cultural identity of the ethnic *Sakalava*, the largest ethnic group of the region, and is a sign of wealth and status. However over the last decade cattle theft has become a major threat to this traditional source of income security and many people have seen their cattle numbers decline steeply.

Our study involved household surveys and key informant interviews in seven villages across two "*fokontany*" (three villages in Mariarano and four in Antanambao) within the commune of Mariarano in western Madagascar's Mahajanga II district. "*Fokontany*" is a local level administrative unit comprised of villages, hamlets or neighborhoods and has elected officials. Antanambao and Mariarano (the latter being the local "capital" of Mariarano Commune) occupy a surface area of 400 km^2 (40,000 ha) with a total population of 3539 (Fig. 2). Out of the 492 km^2 of forests originally present in the commune of Mariarano over 90% is degraded or very degraded according to satellite imagery and ground verifications, with only about 28 km^2 of dense forest fragment present on the Ankatsabe massif within Mariarano fokontany (PGM-E and GOM, 2013). Data were collected during two phases of fieldwork: in September 2014, and a second period of five months from May to October 2015.

3. Methods

3.1. Village selection

To undertake research relating to the associations between forest ecosystem services, including hazard mitigation benefits, and farming livelihoods, three main factors were important in site selection. First, the study region needed to experience hazards linked to heavy rainfall events of different magnitudes and type over the last fifteen years. In the study region, there is an annual rainy season that is influenced by

tropical storms and cyclones affecting Madagascar. Second, there needed to be natural resource dependent farmers present, who by the nature of their primary occupation are exposed to rainfall variability. In Madagascar's Mahajanga II district the predominant farming practice is small scale, rain fed agriculture, much of it in low-lying areas and thus exposed to both variability in rainfall and hazards associated with heavy rains. Third, there needed to be forest users. The residents of the two *fokontany*, Mariarano and Antanambao, actively utilize natural resources from the surrounding landscape and forests. The two *fokontany* fall in two separate sub-catchments. One further reason for selecting this commune was the opportunity to compare between *fokontany* with and without community or other type of formalized management of forests. Mariarano *fokontany* has seen forests under community management since 2000. Forests in Mariarano *fokontany* faced pressures from fire, and forests being cleared for maize farming or cattle grazing, which led to the establishment of community forest management groups, and these pressures continue for forests in Antanambao *fokontany* where to date there are no formal management efforts to reduce these threats.

3.2. Data collection

As key informants (KI) are valuable sources of information and provide explanatory context to the study, they were chosen based upon consultation with the head of the *fokontany*, the recently retired school director who is well known in the *fokontany* and the technical director with the GIZ[1] supported *Programme Germano-Malagache pour l'Environnment* (PGM-E) project. Key informant interviewees included officers of the *fokontany* administrative council, and senior officers of

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[1] GIZ - Deutsche Gesellschaft für Internationale Zusammenarbeit

the two community forest management groups in Mariarano. Subsequently, a household survey with closed and open-ended questions was conducted to identify the nature of agricultural livelihoods, the risks faced by farmers during the rainy season caused by heavy rains, and the value for forest ecosystem goods and services. Specifically, households were asked whether they used particular ecosystem services, their perception of whether the hazards of flooding, sedimentation and debris flow were reduced by nearby forests, and, using Likert scales, their understanding of the relationships between forests and rainfall, and forests and river flows.

Data were collected from seven villages using household surveys and key informant interviews. As there is no list of households living in each village, we used the electoral list obtained from the *fokontany* chief to use as our sampling frame. Many questions in our survey deal with identification of hazard experiences or lean season over a period of five years, thus, we set 26 years as the minimum age of the household head, in order to ensure our sample had households who had been independently farming for at least five years, 21 being the average age at which households farm land independently from their parents (KI 4). We set the upper limit at 70 to ensure we interviewed people who were still actively farming. Within these constraints we selected households randomly using a random number generator. A full household survey with 240 household heads was conducted after pilot testing the survey instrument. 146 households from Mariarano and 94 from Antanambao were interviewed, representing approximately 22.5% of the adult population aged 26 to 65 in the two *fokontany*. In Madagascar, as in many traditional African societies household heads are usually male, thus the majority of our respondents were men, other than in situations with single women or female-headed households.

To identify prevalence of ecosystem service use, hereafter referred to as ES use, we asked respondents about twelve ecosystem services that can be categorized into different types based upon whether they are valued as: food and raw materials as provisioning services because of direct use; nature tourism as income generating options; and, cultural services because of spiritual or religious use options. This list of services was adapted from literature and piloted during the test phase to ensure it was complete (Sodhi et al., 2010; Fagerholm et al., 2012). To identify whether farmers recognized and valued forest regulating services, we posed two categorical questions on the perceived links between local forest cover and hazard reduction benefits, eliciting responses on flood and sedimentation reduction as regulating services as hazard reduction benefits of forests; bringing the total number of ES discussed in this study to fourteen.

To assess participation in forest management, two methods had to be used as no forest management group exists in Antanambao *fokontany*. In Mariarano *fokontany*, where minimum distance from households to forests is 430 m and forests have been under community control since 2000, participants were simply asked whether they were members of either of the two forest management groups (known in Malagasy by the abbreviation "VOI"). For Antanambao where there is no forest management group (and minimum distance to nearest forest is 1 km), we asked respondents if they would be willing to become members if there were such a group (variable "hypotheticalVOI"). A significant proportion (90%, $N = 95$) of Antanambao participants said they would be willing to become VOI members. This contrasts with Mariarano, where only 40% of survey participants ($N = 137$) noted that they were actually members. As the location of the forests used by Antanambao residents is farther and more scattered than in Mariarano, 90% participation is likely to be an over estimate. Thus, we restricted our analysis of participation in forest management groups to the site where these currently exist, the Mariarano *fokontany*.

3.3. Data analysis

Correlation analyses were performed to identify whether respondents who used specific ecosystem services were more or less likely to use another type of service. Chi square tests of independence were also conducted to test whether the two *fokontany* differed in their ecosystem service uses.

To identify farmers' knowledge of forest benefits for agricultural production, specifically hydrological services, we derived a composite score from a series of Likert statements (Table 1). These statements draw upon hypothesized relationships between forest cover and the hydrological cycle in the forest hydrology literature (Kuraś et al., 2012; Lima et al., 2014) and from studies of local perceptions (Wilk, 2000; Meijaard et al., 2013). We refer to this composite score as the "Water Regulation Indicator". Internal consistency reliability of scale responses using Cronbach's alpha test puts this composite indicator within the acceptable range for exploratory analyses with Cronbach's $\alpha = 0.66$ (Gliem and Gliem, 2003; Asano et al., 2006).

To assess whether people valued the role of forests we used membership in the forest management group as the dependent variable in a logistic regression. We use membership in the local forest management group as a proxy for taking action as, in this area, it is the most likely option for people to take collective action to manage the threats to and uses of the forest patches. Madagascar adopted forest decentralization legislation in the late 1990s subsequent to which there is a strong emphasis on encouraging communities to establish community forest management groups (Antona et al., 2004). Independent variables included: standard socio-economic indicators; positive perception of the role of forests in mitigating hazards; and, benefits derived from the use of other ecosystem services, such as food or raw materials.

4. Results

4.1. Household characteristics

Households in our study area ($N = 240$) are predominantly subsistence farmers, with a majority growing all three staple crops: rice, maize and cassava (59%), and 35% engage in some form of wage labour to complement their income. Average household size is 5 individuals (std. dev. = 2.69). Over 76% of households have 1–6 children under the age of fifteen and 56.7 households % have 1–2 adults (15–65 years of age). Almost 30% of the households surveyed own no cattle, 46.2% own 1–5 heads of cattle and 2.9% own over 50. On average 10.4 cups of rice are consumed each day. Literacy levels are generally low with 28% of household heads reporting no formal education and 64% attending but not necessarily completing primary schools.

4.2. Forest ecosystem services, including hazard mitigation services, and livelihood benefits

Here we present results on the ecosystems services that are most and least valued by farmers based upon the proportion of respondents who answered "yes" to using these, whether there are differences in ES use by sites, and how socio economic factors may affect respondents' use of various services. Table 2 presents the proportions of respondents in the two sites that are dependent upon these services.

Table 1
Likert scale statements used to create a composite indicator for water regulation services. Responses for each statement ranged from 1 - do not agree at all to 5 – agree a lot.

1	The forest cover in this region plays an important role in bringing rains
2	The rainy season here is generally sufficient for replenishing the water flow in the river each year
3	There is more stable supply of water in the river, streams and lakes because of the forest cover in this region
4	Forests are important for providing reliable supply/availability of water for irrigating your rice fields
5	Forest cover in this region plays an important role in supporting your agricultural production capacity

Table 2
Proportions of survey respondents using different forest ecosystem services from two sites with and without formalized forest management regimes in Madagascar.

| Site		Antanambao (No forest management group present)			Mariarano (Two forest management groups existing)		
		Yes	No		Yes	No	
i	Food	(%)	(%)	N	(%)	(%)	N
	Honey	51.1	48.9	92	45.5	54.5	145
	Wild vegetable/fruits	79.3	20.7	92	71.9	28.1	139
	Fish	91.2	8.8	91	73.4	26.6	139
	Tenrecs	30.4	69.6	92	37.1	62.9	143
ii	Raw materials						
	Fuelwood	96.7	3.3	92	97.8	2.2	137
	Polewood	95.6	4.4	91	95.0	5.0	139
	Wood for charcoal	19.6	80.4	92	32.2	67.8	143
	Raphia, satrana	86.8	13.2	92	83.4	17.9	140
iii	Cultural services						
	Medicinal plants	80.4	19.6	92	83.3	16.7	138
	Sacred spaces	74.7	25.3	91	44.8	55.2	143
	Religious spaces	75.8	24.2	91	52.4	47.6	143
	Tourism benefits	20.9	79.1	91	21.0	79.0	143
iv	Hazard reduction						
	Believe forests reduce flooding	46.7.	53.3	92	64.2	35.8	142
	Forests reduce sediments/debris flow.	64.1	35.9	92	78.7	21.3	141

The household survey identified a much greater level of dependence upon the extraction of raw materials from the forest than that of food items, cultural services, or hazard mitigation benefits: on average 91.6% and 93.1% of the respondents in Mariarano and Antanambao respectively extract fuelwood, timber and plants like raphia or satrana from the forest and surrounding mosaic compared to 56.6% and 63.1% respectively of the respondents who engage in honey production, catching fish or harvesting tenrecs, a small insectivorous mammal, and wild vegetables. Residents of Antanambao are more likely to report fishing than those of Mariarano (Chi square = 11.1, p = 0.001). A significantly smaller proportion of respondents acknowledge extracting wood to produce charcoal (31.1% in Mariarano and 19.4% in Antanambao) (Table 2). Amongst the raw materials used, polewood is used by 95.3% of the respondents, with all reporting that they extract polewood for household needs only, and not for sale. In contrast, those who produce charcoal (26.4% of total respondents) do so predominantly as an income source, with 69.6% selling half or more of the charcoal produced. None of the household characteristics examined such as years farming, total household size, cups of rice consumed per day, cattle owned, or education levels are associated with engaging in charcoal production. Charcoal production is banned within the community-managed forests in Mariarano, yet a significant association was found between living in Mariarano and practicing charcoal production than in Antanambao where there is no such rule in place (Chi Square = 4.5 and p = 0.034).

While 76.7% of all respondents fish, only 19.8% of those who practice fishing sell half or more of their catch. In contrast, of those who depend upon the forests for honey production (N = 97), 59.7% sell anywhere from half to all of their honey production (Fig. A.1). Honey is seen as both a commodity that can be consumed at home and sold to augment income, with a litre of raw honey selling for 4000–6000 Ariary (1.22 to

Table 3
Socio economic characteristics as determinants of different ecosystem service uses (N = 240).

Ecosystem services used	Socioeconomic variables	B	S.E.	Sig.	Exp (B)	95%C.I.for EXP (B)	
						Lower	Upper
Use of raphia, satrana	Years farming	0.047	0.018	0.008	1.048	1.012	1.085
	Education level	−0.561	0.304	0.065	0.571	0.315	1.035
	Adults 15–65	0.581	0.246	0.018	1.788	1.104	2.896
	Constant	2.129	0.793	0.007	8.404		
Charcoal production	Years Farming	−0.026	0.015	0.082	0.974	0.946	1.003
	Number of staple crops grown	0.977	0.306	0.001	2.657	1.457	4.844
	Constant	−3.734	0.948	0	0.024		
Seeing income benefits from tourism	Education level	0.617	0.276	0.025	1.852	1.079	3.18
	Wage income	0.522	0.172	0.002	1.685	1.204	2.359
	Constant	−2.96	0.89	0.001	0.052		
Honey production	Total household size	0.24	0.1	0.016	1.271	1.046	1.545
	Cattle owned	0.346	0.13	0.008	1.41	1.1	1.82
	Constant	−1.309	0.613	0.033	0.27		
Hunting tenrecs	Wage income	0.493	0.163	0.002	1.637	1.19	2.251
	Adults 15–65	0.284	0.136	0.037	1.329	1.017	1.736
	Constant	−2.748	0.808	0.001	0.064		
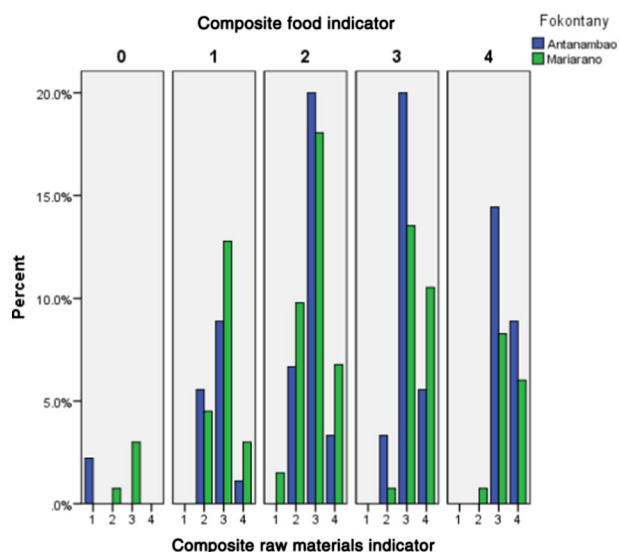
Fig. 3. This figure shows the level of dependence upon the four different raw materials (fuelwood, charcoal, polewood and raphia/fiber plants) discussed here in comparison to the food items (honey, fish, wild vegetables/fruits and tenrecs). For example, households who do not depend upon any of the food items, still rely on 1, 2 or 3 raw materials (left hand panel).

1.82 USD) in the dry season when the quality of honey produced is optimum. Greater total household size and to a lesser degree, financial capital (proxied by the number of cattle owned) significantly influence engagement in honey production (Table 3). Honey is also used for medicinal purposes, nutrition and for traditional rituals in Mariarano; uses which have allowed members of the Mariarano VOI Tanteraka to convince others in the *fokontany* to support forest protection and regeneration in order maintain this benefit in the short and long term (pers. comm. J.E.R, KI 3 and 4). To date there is no organized cooperative through which honey producers can get a stable and fair price. Individual shopkeepers and small business owners with ties to the city of Mahajanga dominate the trading channels though there are efforts underway by local development groups like the PAGE/GIZ program to support producers through setting up a cooperative, a honey processing unit and facilitating access to markets for its members (pers. comm., J.E.R).[2]

All of the respondents who hunt tenrecs (34.5% of respondents), and collect wild vegetables and fruits (75.5%) report doing so for household consumption only. The number of adults (aged 15–65) in a household is a small but significant positive factor influencing the likelihood of hunting tenrecs (Table 3) indicating that those households with a higher number of able-bodied adults tend to take part in this activity more than others. However, hunting may be an opportunistic activity, providing a source of protein during the open season for tenrec collection rather than a regular dietary need. Those who hunt tenrecs are also likely to harvest wood for charcoal from the surrounding landscape (Pearson's $r = 0.27$, $p < 0.001$). Interestingly hunting tenrecs, collecting wild vegetable and fruits and relying upon raphia and other plants for making mats and roofs, are seen as significant predictors of considering forests as important safety net providers during times of stress such as illness or a bad harvest (Table A.1). Over 44% of the participants depend upon three or four dietary items from the forest and surrounding habitats while over 82% depend upon three or four of the raw materials (Fig. 3).

Hazard mitigation benefits in the form of reduced flooding and reduction in the amount of sediment and debris flowing onto rice fields are valued by 58.1% and 73.0% of the respondents in our survey. We do not find any association between benefits from food, raw materials or tourism income and viewing forests as important for hazard reduction. Our survey finds that the *fokontany* to which an individual belongs influences the value for hazard mitigation services. In Mariarano, the site with forest management, people are significantly more likely to value these benefits, as compared to Antanambao, the site without forest management (Chi square = 8.07 and 6.01, df 1, $p = 0.005$ and 0.014 for flooding and sedimentation respectively). A simple explanation for this is possibly the fact that while the villages that make up Mariarano *fokontany* are considerably closer to the small hills that are forested, in Antanambao, the landscape is described variously as a "bowl" or basin, which tends to collect water and is seen to flood each year (KI8, August 2015). In addition, as is evident from Fig. 1, there is less forest cover around the sites where people farm and live in Antanambao.

Income generated by being involved in tourism related activities is a benefit seen by only 20.9% of the respondents. The main sources of tourism income are the three research camps set up each July–August. Common sources of employment are tourist guides, camp guards, and through transporting baggage between sites, selling food items and locally produced handicrafts such as baskets and mats woven from fiber from satrana palm fronds. The small number of beneficiaries of tourism may be a function of the hiring capacity of the seasonal research based tourism existing in Mariarano. The secondary road leading to Mariarano is impassable in the rainy season, and this would limit a longer tourist season. 79% of household heads that benefit from local tourism have at least some formal primary school education. Education is positively correlated with acquiring benefits from tourism, and interestingly our results also show that respondents who benefit from tourism are also likely to hunt tenrecs during the open season in Mariarano *fokontany* ($r = 0.197$, $p = 0.003$).

81.9%, 55.2% and 60.9% of the household's surveyed valued medicinal plants, sacred areas and areas important for religious ceremonies. Medicinal plants are collected locally and within the forests by a majority of those interviewed and used to treat common stomach ailments and fevers. The continuation of these uses and beliefs is balanced against the need for land, timber, and other resources, and against the pressures of migratory groups who may not hold the same beliefs. Indeed we find that respondents in Antanambao are significantly more likely to hold beliefs in sacred sites in the surrounding landscape than those in Mariarano (Chi-square = 21.674, df = 1, $p < 0.001$)

Socio-economic characteristics of households such as cattle ownership as an indicator of relative wealth, the average cups of rice eaten per day as an indicator of food needs per family, the length of time spent farming in years, the total household size and education levels do not show any relationship with beliefs about hazard mitigation as a forest service, contrary to what may be hypothesized based upon results from other studies (Sodhi et al., 2010). In Antanambao, there is significant positive relationship between education and those who benefit from tourism (Pearson's correlation, $r = 0.218$, $p = 0.038$). Overall our results support our first hypothesis that seasonally dry tropical forests are important for livelihood benefits and for hazard mitigation services as seen by farmers.

4.3. Knowledge of the relationships between forests and generation of ecosystem services

Three important questions are analysed here: first, do farmers understand the relationship between forests and the hydrological cycle? Second, does an understanding of this relationship lead to less extractive forest uses? Third, does a good understanding of these linkages lead to valuing the hazard mitigation benefits of forests?

4.3.1. Farmers' understanding of the relationship between forests, the hydrological cycle and agricultural production

Most participants score high on the water regulation composite indicator created from a series of Likert statements (Table 1) with the median score being 20 out of a maximum of 25 for the total sample. The mean score for this composite indicator is 19.6, ($n = 231$) indicating that respondents in both sites understand the significance of forests for their daily lives and livelihood through the regulation of water absorption, flow and availability for agricultural production. We do not find education as a significant factor in scoring highly on this indicator, with age the only household characteristic seen as a predictor of respondents' knowledge of the links between forest cover and water regulation, and that too only in Mariarano.

4.3.2. Forest – hydrological cycle linkages and engaging in exploitative forest uses

We hypothesized that having a good understanding of the forest-hydrological cycle linkages should be associated positively with less exploitative uses of forests. Producing charcoal is seen as an illicit activity especially in Mariarano, though to what extent is questionable. Nevertheless it is one of the most important proximate causes of broader forest loss (Ahrends et al., 2010), thus we use engagement in charcoal production as an indicator of exploitative uses of the forest. Overall for the two sites together engaging in charcoal production is negatively associated with scoring higher on water regulation indicator at the 90% significance level ($r = -0.115$, $p = 0.08$). Engaging in charcoal production is seen to be a significant negative predictor of understanding the linkages between forests and water regulation for respondents in Mariarano (Table A.2). Our results support our assumption that a more positive understanding of the forest-water cycle linkages would result in less exploitative uses of forests.

4.3.3. Forest – hydrological cycle linkages and valuing forests for hazard reduction benefits

The third hypothesis that we test here is whether a greater level of understanding of the linkages between forest cover and water regulation is associated with the likelihood of holding a positive attitude towards the hazard mitigation benefits derived from forests. Our results indicate a small, but significant relationship at the 90% significance level between higher scores on the water regulation indicator and a positive attitude of the flood hazard mitigation benefits of forests ($r = 0.117$, $p = 0.07$, $N = 226$), however no such association is evident with the attitude towards sedimentation reduction by forests. Disaggregating the two sites, we find that the water regulation indicator is a significant predictor of perceiving flood reduction benefits from forests for respondents in Mariarano *fokontany* ($p = 0.09$), but not in Antanambao (Table A.3).

4.4. Do farmers value forest ecosystem benefits sufficiently to take action and if not why not?

Honey production and benefiting from tourism are the only two forest benefits' variables that significantly predict participation in a forest management group, the proxy used for taking action (Table 4). Adding the two variables that measure hazard mitigation benefits does not improve the model output. None of the ES used are significant predictors for Antanambao, however as already stated we have a likely over estimate of people willing to participate in forest management which would influence the statistical tests. As seen from results in Section 4.2, collecting timber is not an economic activity, and all of the respondents who collect wild vegetables or tenrecs do so for household consumption. These results – that only direct income generating activities, specifically honey production and tourism that rely on good natural forests, are seen to influence participation - are explained to a certain degree by the socioeconomic attributes characterizing the household (Table 3). While hazard experiences may be of a sufficient magnitude, the lack of a causal relationship between positive valuation of flood reduction benefits from forests and taking action to sustain these benefits for the long term by protecting forests reflects to some degree the variability in these services and the complexity of the linkages between forests and the water cycle as mentioned in Section 1 and the basic reality that people are more willing to act on tangible benefits in such scenarios where daily needs dominate decision making of the majority. Education levels and cattle ownership are the only socioeconomic, household characteristics that predict whether respondents participate in forest management in Mariarano (Table 4).

5. Discussion

5.1. Forest ecosystem services, including hazard mitigation services, and livelihood benefits derived by smallholder farmers

Our results indicate a strong dependence upon food, raw materials and cultural benefits of dry forest ecosystems in both our sites, reinforcing existing research findings that seasonally dry tropical forests play an important role in the daily lives of forest frontier communities (Maass et al., 2005). We find that farmers in northwestern Madagascar recognize the role of local forests in reducing sediment and debris flow, and in reducing the magnitude of floods in agricultural fields. Scientists, policymakers and communities in different regions of the world share these perceptions of the hazard mitigation benefits of forests to differing degrees (Chomitz and Kumari, 1998; Wilk, 2000; Balmford et al., 2002; Maass et al., 2005; Silvano et al., 2005; Hauck et al., 2013). Our study provides insights on how forest edge communities in small catchment areas view the role of forests in reducing storm hazards, adding to the sparse literature on storm hazard mitigation benefits of forests in the tropics (Maass et al., 2005; Meijaard et al., 2013). Significant perception of forests as safety net predictors during times of stress correspond to results from other studies that demonstrate reliance by households upon forest resources in the immediate aftermath of a natural disaster or other household income reducing events (Shackleton and Shackleton, 2004; Völker and Waibel, 2010; Liswanti et al., 2011). Various ethnic groups in Madagascar place a spiritual value on nature as a link between the living and the ancestors; these cultural norms serve as means to continuing the kinship with the departed, which in some cases are linked to resource conserving behaviour such as a ban on

Table 4
Determinants of participation in forest management for Mariarano *fokontany* (n = 138).

Determinants of participation	B	S.E.	Sig.	Exp (B)	95% C.I. for EXP (B)	
					Lower	Upper
Honey production	0.877	0.414	0.034	2.403	1.068	5.408
Places that provide income benefits from tourism	1.290	0.530	0.015	3.634	1.287	10.260
Forests reduce floods belief	0.585	0.452	0.195	1.795	0.741	4.349
Forests reduce sedimentation/debris flow belief	−0.402	0.525	0.444	0.669	0.239	1.873
Education level	0.934	0.381	0.014	2.544	1.207	5.365
Cattle owned	0.433	0.169	0.011	1.542	1.106	2.149

Nagelkerke R square = 0.22.

hunting lemurs or keeping some forests intact, thus providing a refuge for threatened species and habitats (Horning Rabesahala, 2004; Jones et al., 2008; von Heland and Folke, 2014). These social and cultural norms may see some erosion with time, yet, amongst the predominantly *Sakalava* ethnic group in Mariarano commune we can see the ancestral norms in place and influencing many people value for cultural services of deciduous forests.

5.2. Knowledge of the relationships between forests, generation of ecosystem services and support for community forest management

Our results on the understanding held by farmers of the linkages between forest cover, rainfall, absorption of water and the supply of water in the streams are corroborated by Wilk (2000) who find similar locally held knowledge of these linkages in two watersheds in rural India and Thailand. Local knowledge of forests and water regulation links as shown by our results and these other studies correspond to broader scientific understanding of the role of forests in delivering hydrological services (Bruijnzeel, 2004; Brauman et al., 2007). However, a better understanding of these linkages is related to the valuation of the flood regulation services offered by forests, but not with reduction of excessive sedimentation or debris flows. Nevertheless we find that an awareness of hazard reduction benefits does not necessarily translate into willingness to actively support or participate in forest management. This runs counter to recent research which suggests that farmers in developing countries who value soil erosion reduction services generated by forests are more willing to participate in forest management, for example, through demonstrating a higher willingness to pay for forest management (Danquah, 2015; Amare et al., 2016).

We suggest that factors that prevent people from taking action are as important now as they were when decentralization efforts began in Madagascar and elsewhere (1990s, early 2000 for Madagascar). These factors include: marginalization of segments of the community, the economic costs of membership payments however small these fees may be within the local context; distrust of external actors who are seen as the source of formalizing community forest management and instituting regulations against the clearance of forests for charcoal or grazing land (Agarwal, 2001; Aymoz et al., 2013; Cullman, 2015); and a tension between customary norms to govern the use of forests and engaging in formal forest management (Cullman, 2015). Furthermore, it may simply be too difficult for some members of the community to spare the time required to attend meetings and participate in activities such as reforestation programs as members of a forest management group, thus leading to the so called "free rider" phenomenon in community forest management (Klooster, 2000). Further detailed empirical work is needed to identify, under what socio-economic or cultural circumstances, local farmers' knowledge of risk mitigating services generates a positive or a negative engagement with formal forest management groups.

Indeed, the majority of studies that investigate factors influencing participation in community forest management groups in the tropics identify demographic variables or forest derived economic benefits as important determinants (Lise, 2000; Dolisca et al., 2006; Coulibaly-Lingani et al., 2011; Méndez-López et al., 2015). While our study finds income benefits derived from forests to be significant determinants of support for forest management, we do not see this relationship between management support and heavy dependence upon the forests for raw materials, food or cultural uses, contrary to earlier studies in India, Burkina Faso and Kenya (Lise, 2000; Coulibaly-Lingani et al., 2011; Musyoki et al., 2013), which show that high dependence upon forest resources influences individual choices to participate in forest management groups. Instead our results indicate that the only two significant predictors of participation in forest management groups are: activities that generate income and need forests, namely honey production and tourism. Natural forest are seen as important providers of nectar and pollen necessary for honey production (Sande et al., 2009) thus benefiting honey production from the forest and satrana dominated grasslands as seen in our research (KI 3, pers. comm. JER). Valuing forests as important for honey production is a significant determinant of supporting community management based as shown here and supported by studies in other regions (Amare et al., 2016). By participating in forest management and being interested in the short and long term sustainability of accessing the joint benefits from honey production, these users reflect one of the attributes of successful local organization made by Ostrom et al. (1999). Our findings also corroborate those of other studies that show the importance of financial and human capital as essential elements of livelihood diversification strategies (Chopra, 2002).

The second forest dependent factor that is linked to participation in forest management groups in our sites is earning income from tourism linked activities and business opportunities. Income from tourism is seen to influence participation in forest management in other regions, for example, in Nepal (Mehta and Heinen, 2001). We see that receiving tourism benefits in Mariarano, the site with two forest management groups is a predictor also for hunting tenrecs in the open season, suggesting that those who benefit from tourism are also better informed and more able to participate in collecting these resources during the open collection season in March. Additionally, we find that education is an important determinant in benefiting from income opportunities brought by tourism in the area. A minimal literacy level may be a strong indicator of the ability of an individual to participate in activities, e.g. to set up small businesses, to seek out employment with others, to volunteer for trainings as forest guides and even a requirement as being a forest guide requires the ability to read and communicate with outsiders, thus favouring those with higher education levels (Gezon, 2014), which may be correlated with higher wealth and other assets (Coria and Calfucura, 2012). We have shown that simply using ecosystem services to garner wider support for forest management is not likely to succeed unless there are significant tangible benefits to forest dependent communities in the vicinity of these forests. Furthermore, the relationships between the ability to obtain a forest based income and engagement in forest management groups are not always linear and need to be further investigated.

Education and relative wealth are two of the socioeconomic characteristics of households that influence participation in forest management groups in our study, as in the case of Burkina Faso and Sri Lanka (Nuggehalli and Prokopy, 2009; Sodhi et al., 2010; Coulibaly-Lingani et al., 2011). Education levels are important not only as indicators of formal knowledge, but as channels for empowerment to create the capacity to participate in group decision making and being heard, thus creating facilitating conditions for individuals to (Nuggehalli and Prokopy, 2009) participate in forest management groups. Relative wealth influences everything from power dynamics to the ability to invest in the financial or human capital as seen from several studies around the world (Leach et al., 1999; Armitage, 2005). These factors ultimately influence an individual's capacity to engage in business ventures to gain from tourism or other activities like honey production.

6. Conclusions

Through this research we contribute to the wider body of knowledge on forest ecosystem services, expanding the understanding of storm hazard mitigation services of dry, deciduous forests, the livelihood benefits derived by smallholder farmers from these forests, and how these influence local support for forest management initiatives. We show that not only do farmers derive livelihood benefits from seasonally dry tropical forest fragments in Madagascar, but they also perceive a positive role for forest cover in hydrological processes including sedimentation and flood hazard control. However, this extensive use of forest services does not overwhelmingly translate into a willingness

to take action to support forest management, and this is an important implication for forest policy and management. We demonstrate the importance of factors such as securing complementary income from forest based honey production and tourism, relative wealth and the education levels to participation in forest management. These results reflect the heterogeneous nature of different households comprising a community and consequently the differing abilities of individuals to take advantage of institutions and structures established to manage forest resources and derive benefits. We suggest that efforts to improve and broaden support for forest management should focus attention on the beneficiaries of forest-dependent income generating activities and identify steps to broaden participation in these ventures.

Based upon our results, we suggest two main research areas to investigate further. The first is the relationship between the use of provisioning services and the acknowledged benefits of regulating ecosystem services, While hazard reduction services are widely perceived as benefits from forest cover we did not find a significant relationship (either positive or negative) between these variables and other ecosystem uses/benefits or with supporting forest management. A second area for further investigation is whether the local understanding of forests and provision of hazard mitigation services is obtained through observations and experiences or through exposure to external projects and education programs. Further examination of how the knowledge of forest-hydrological linkages is formed and how it is translated into decision making on forest and land use management by farmers is important for both forest policy and for considering how broader land use policy can integrate rainfall linked hazard mitigation services provided by forests in such settings. Finally, we found only two out of the fourteen ecosystem services valued by study respondents significantly influence participation in forest management groups, again bringing to bear the question of what motivates collective action and

participation in forest management. Unless we are better able to identify what type of ecosystem service benefits motivate involvement in forest management and what the barriers to participation may be, it is unlikely that appropriate forest management institutions will emerge in the case study region and elsewhere. Local knowledge of ecosystem services and the rationale behind household decision making around forest use is important for effective policy interventions in forest management, the long-term sustainability of forest resource use and conservation and land use policy.

Appendix A

Table A1
Ecosystem services uses of forests as predictor variables of perceiving a safety net function of forests.

| Predictor variables	Unstandardized coefficients		Standardized coefficients	t	Sig.	95.0% confidence interval for B	
	B	Std. error	Beta			Lower bound	Upper bound
(Constant)	2.866	0.242		11.852	0	2.389	3.342
Collecting wild fruits and vegetables	0.842	0.193	0.294	4.371	0.00	0.462	1.223
Collecting raphia, satrana and other plants for artisanal products	0.486	0.238	0.137	2.044	0.042	0.017	0.954
Hunting tenrecs	0.332	0.168	0.131	1.975	0.05	0.001	0.664

Table A2
Engaging in charcoal production as determinant of respondents' knowledge of forest-water regulation linkages, by fokontany.

Fokontany		Unstandardized coefficients		Standardized coefficients	t	Sig.	95.0% confidence interval for B	
		B	Std. error	Beta			Lower	Upper
Antanambao	(Constant)	19.507	0.547		35.669	0.000	18.420	20.594
	Charcoal producer	−0.562	1.230	−0.048	−0.457	0.649	−3.006	1.881
Mariarano	(Constant)	20.053	0.437		45.927	0.000	19.190	20.917
	Charcoal producer	−1.495	0.779	−0.163	−1.918	0.057	−3.036	0.046

Table A3
Water regulation score as a determinant of belief in the flood and sedimentation reduction services of forests (N = 226).

Parameters	B	S.E.	Sig.	Exp (B)	95% C.I. for Exp (B)	
					Lower	Upper
Flood reduction belief	0.054	0.031	0.080	1.056	0.993	1.122
Constant	−0.700	0.618	0.258	0.497		
Sedimentation reduction belief	0.041	0.033	0.212	1.042	0.977	1.112
Constant	0.174	0.652	0.789	1.191		
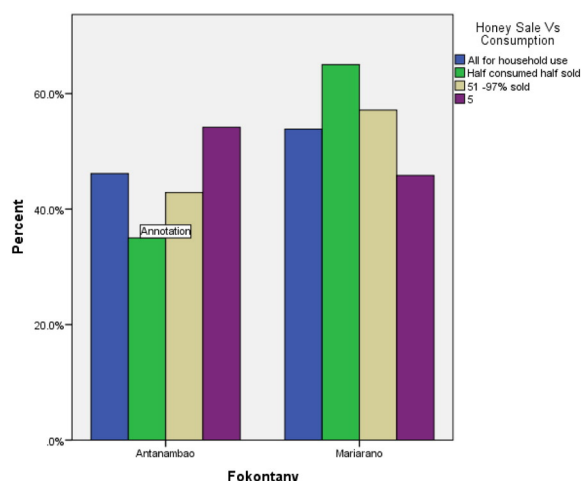
Fig. A1. Proportion of households producing honey only for home consumption, for a mix of home and sale and for only selling for income.

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