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Strategies of smallholder farmers for coping with the impacts of cyclones: A case study from Madagascar

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ABSTRACT

In many tropical countries, smallholder farmers are highly vulnerable to cyclones and experience significant crop losses, food insecurity and income loss when cyclones hit. Madagascar has one of the highest rates of cyclones globally and a population comprised primarily of smallholder farmers, yet there is little information on how Malagasy smallholder farmers prepare for and cope with the cyclones. We conducted interviews with 200 Malagasy smallholder farmers following the impacts of cyclone Giovanna (a category 4 cyclone that struck in February 2012) to understand how farmers prepared for the cyclone, how the cyclone impacted their livelihoods and what strategies farmers used to deal with these impacts. Most farmers prepared for the cyclone by storing clean water; some also secured their buildings and stored food and seeds. Cyclone Giovanna caused substantial damage to crops, stored grains and houses, and significantly reduced farmer food security. Farmers coped with the cyclone by replanting crop fields, rebuilding homes with local materials, reducing consumption of staple foods, harvesting wild foods and finding temporary work to buy food. Informal social networks were critical for providing food and rebuilding houses. There is an urgent need for governments, donors, and development organizations to reduce the vulnerability of Malagasy smallholder farmers to cyclones by improving early warning systems, increasing farmer preparedness for cyclones, creating formal safety nets to help farmers access food and essential supplies following cyclones, and promoting the use of adaptation measures to enhance the resiliency of smallholder farmers to future climate shocks.

1. Introduction

Tropical cyclones are known to have significant global impacts on human health, livelihoods and economic activity. It is estimated that 35% of the world's population is affected by cyclones [22] and that cyclones affected 466 million people from 1980 to 2009 [14]. In addition to the immediate impacts on human health, livelihoods and local economies, severe cyclones often set back a country's development by several decades [22], as seen in Honduras after the impacts of hurricane Mitch [1].

Madagascar is one of the tropical countries that is most affected by cyclones globally and has one of the highest rates of cyclones in

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Africa [11,14,47]. Each year an average of 3–4 tropical cyclones originate in the Indian Ocean and the Mozambique Channel and hit Madagascar during the cyclone season from November to April [15,26,47,52]. The high winds, excessive rainfall and associated flooding from cyclones have devastating impacts on both the national economy and local livelihoods [19,22,33]. Cyclones damage infrastructure, flood agricultural areas, destroy crops, injure cattle, threaten food security, contaminate water supplies, increase the incidence of water-borne diseases, and cause human injuries and sometimes deaths [11,42]. The associated economic and humanitarian costs of natural disasters in Madagascar are enormous: it is estimated that floods, drought and cyclones have affected more than 11 million people in Madagascar in the last 35 years and resulted in roughly 1 billion US dollars of damage [47,51]. Across Madagascar, about five million people (or ~25% of the entire population) are estimated to be vulnerable to natural disasters such as cyclones, droughts and flooding [48]. The frequent occurrence of cyclones is also a major contributor to the country's extremely high levels of poverty and food insecurity [11,48]. Climate models project that Madagascar is likely to have fewer but more intense cyclones in the future due to climate change [26,45], which means that finding ways to reduce the vulnerability of the Malagasy population to these cyclones will become even more critical in the near future.

While cyclones affect all sectors of society, the most vulnerable communities are usually those that are poor, marginalized, and without access to formal safety nets [6,12,20,32]. Studies from other countries that are regularly affected by cyclones, such as Bangladesh (e.g., [2,49]), India [3,4], Mozambique [34] and Indonesia [10], among others, have highlighted that smallholder farmers are particularly vulnerable to cyclones. Smallholder farmers (generally defined as those having less than 2 ha of land; [46]) are vulnerable to climate shocks due to their dependence on rain-fed agriculture, limited areas of arable land, high poverty levels, food insecurity, lack of access to information and limited resources to prepare for and cope with the impacts of cyclones (e.g., [6,30,32]). The coping strategies of smallholder farmers to climate shocks and longer term adaptation plans are often place-specific and adapted to local circumstances [8]. Consequently, detailed information on how smallholder farmers in particular landscapes are already responding to climate shocks is needed to inform the development of strategies and policies to their vulnerability to climate shocks and to enhance their adaptive capacity [4].

In Madagascar, smallholder farmers are known to be at great risk from cyclones [19], but to date there have been no studies on the specific impacts they experience and how they cope with these impacts. An estimated 71% of Malagasy farmers are smallholders [23,29], with a national average upland rice area per farmer of only 1.28 ha [54]. Most Malagasy smallholder farmers practice subsistence farming, depending on agriculture both for food security and for household income, and are seasonally food insecure [5,13,14,19,37]. Most smallholder farmers are also extremely poor, with an estimated 87% of smallholder farmers falling below the national poverty line [23]. As a consequence, Malagasy smallholder farmers are extremely vulnerable to extreme weather events that reduce agricultural productivity or cause crop loss.

The overall objective of our study was to understand how Malagasy smallholder farmers prepare for and cope with the impacts of cyclones, using a case study of how smallholder farmers reacted to cyclone Giovanna that hit Madagascar in February 2012. Cyclone Giovanna was a category '4' cyclone (on the Saffir-Simpson Hurricane Intensity Scale of 1–5, where 1 is the weakest and 5 the strongest [27]; with winds of up to 269 km per hour and a total of 355.6 mm of rainfall occurring over three days [18]. The cyclone is known to have affected at least 246,000 people, destroyed >44,000 houses, damaged >27,000 houses and damaged at least 12,517 ha of agricultural land across Madagascar, but the real impact was likely greater given that information on impacts was only reported by 250 of the 697 municipalities in Madagascar [7]. We conducted surveys of 200 farmers to: a) explore how farmers prepared for cyclone Giovanna and how effective their preparations were in reducing vulnerability; b) document the specific impacts of the Giovanna cyclone on agricultural production and farmer livelihoods (including impacts on income, health, housing and food security); and c) examine how farmers coped with the impacts of cyclones on their farming systems and livelihoods and how effective these coping strategies were in reducing their vulnerability.

While there are existing government assessments of the overall impacts of individual cyclones (including cyclone Giovanna) at the district, regional and national levels [7,17], to our knowledge, this is the first study in Madagascar to collect detailed household-level data on the specific impacts of cyclones on smallholder farmers and to examine the coping strategies used by farmers to deal with these impacts. Our study provides unique insights into how smallholder Malagasy farmers are affected by cyclones and highlights key measures which could be incorporated into Madagascar's National Action Program for Adaptation to Climate Change for Agriculture (PANA), the National Strategy for Risk Management (SNDRM; [50]), the National Action Plan for Food Security (PANSA), and the Poverty Reduction Strategy, among other national strategies. Our results also provide valuable information for donors and development agencies interested in improving food security, alleviating poverty, and reducing the overall vulnerability of Malagasy smallholder farmers to climate change. In addition, our study illustrates the complexity of addressing smallholder farmer vulnerability to extreme weather events, an issue which is relevant to other cyclone-prone developing countries (e.g., [3,10,32]).

2. Materials and methods

We examined how smallholder farmers prepared for and responded to cyclones in two agricultural landscapes located along the eastern escarpment of Madagascar – the Ankeniheny Zahamena Corridor (CAZ) and Nosivolo, both of which were significantly impacted by cyclone Giovanna (Fig. 1). The CAZ landscape is located adjacent to the Ankeniheny Zahamena forest, one of the largest remaining rainforests in Madagascar, while Nosivolo is a riverine protected area located further south in the District of Marolambo. Both landscapes are characterized by a mix of agricultural land, regenerating forests (from slash and burn) and remnant forests, and are inhabited by smallholder farmers who typically cultivate less than 2 ha of land ([19]; Table 1). The traditional and most common agricultural practice in both sites is the use of slash and burn ('tavy') for rice production for home consumption [39,43]. Other crops grown in tavy areas include cassava and corn. In the lowland areas of each site, farmers also grow irrigated rice and cash crops. Some farmers also raise poultry on a small scale or produce charcoal for sale to urban areas. Most farmers in the region live below the national poverty line, are food insecure for several months per year [19] and have large families. Their houses are constructed of local materials such as timber, mud bricks and the bark or leaves of *Ravenala madagascariensis* and *Raphia ruffa* [19]. Both areas are remote and have poor road infrastructure. Roads in Nosivolo are only accessible during the dry season. In CAZ, only the southern and western parts of the landscape are accessible by road year-round.

In order to assess the impacts of cyclone Giovanna on farmer livelihoods, we randomly selected a total of 10 selected communities (7 in CAZ and 3 in Nosivolo) from a list of areas which had been impacted by the cyclone. We surveyed more communities in the CAZ region than in Nosivolo because distinct regions of CAZ

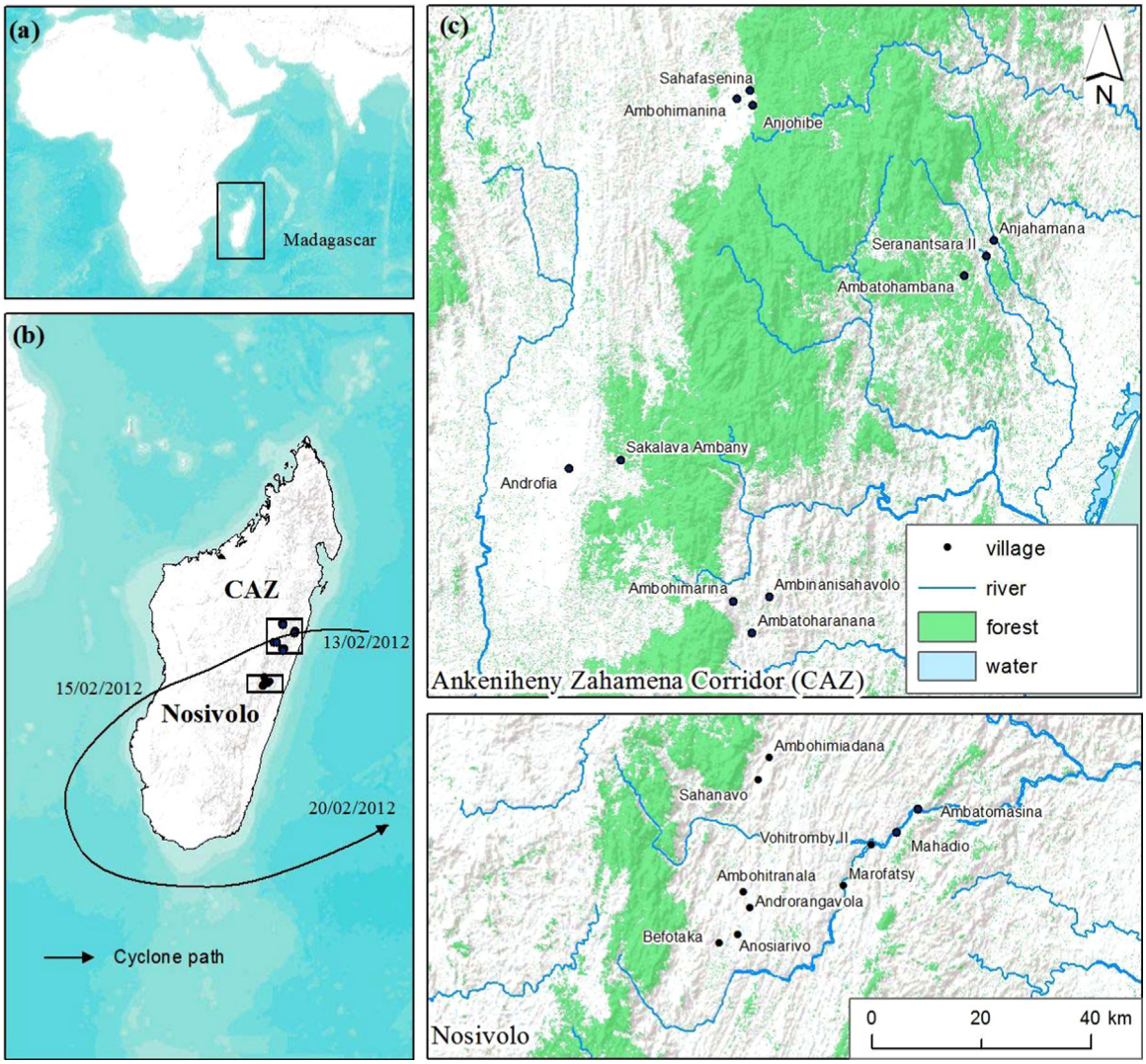

Fig. 1. A map showing (a) the location of Madagascar; (b) the pathway of the Giovanna cyclone across Madagascar in February 2012 (with date and time of landfall indicated), and (c) the location of the villages in the two study landscapes (CAZ and Nosivolo) where the impacts of cyclone Giovanna on smallholder farmers were examined.

suffered different levels of exposure to the cyclone, while in Nosivolo, all communities were significantly impacted by the cyclone. In each of the ten villages, we randomly selected 10 households from a list of smallholder farmers and interviewed the wife and spouse in the same household (i.e., 200 people total, 100 men and 100 women). We interviewed both men and women because we were interested in seeing if men and women prepared for and/or responded differently to the cyclone. In cases where the head of the household was a woman, we also interviewed the most senior man in the same household.

The semi-structured survey was designed to collect information on farmer perceptions of the intensity of the cyclone, the impacts of the cyclone on their livelihoods, the preventative strategies used by farmers to prepare for the cyclone, the coping strategies used, and the support they received prior to and following the cyclone. All interviews were conducted inside or outside of the farmers' house and typically lasted 45 min. Male interviewers were responsible for interviews with the household head, while the women were interviewed by female interviewers. All household surveys were conducted in March, 2012, within a month after cyclone Giovanna hit. After each individual survey, we verified the data collected in each village through focal group discussions. All data were analyzed using descriptive statistics. Since responses from men and women were not statistically distinct, our summary statistics include answers from both men and women farmers (n=200 farmers).

3. Results

3.1. Preventative strategies used by farmers

Farmers undertook a variety of preventative actions to reduce the impact of cyclone Giovanna on their households (Table 2). Seventy percent of the farmers stored clean water to use following the cyclone. Other less common strategies included securing the roof with sandbags, storing food to ensure the family had food to eat following the cyclone, and moving rice seeds stored on the floor of their homes in plastic bags onto the table to ensure they would not be damaged by floods. Only 22% of farmers moved livestock to more secure locations (e.g., higher ground or inside home). Less than 20% of farmers sought refuge in churches, schools or other buildings. On average, farmers implemented a mean of 1.9 preventative actions each.

Table 1
Biophysical and social characteristics of the landscapes where the impacts of cyclone Giovanna on smallholder farmers were explored. Data on population size are from 2007/2008 and represent the most recent census information [29]. Data on farm size, family size and main crops are based on Harvey et al. [19], while data on poverty levels come from INSTAT [23].

Characteristics	Variable	Ankeniheny Zahamena Corridor (CAZ)	Nosivolo
Landscape characteristics	Size of study landscape (ha)	382,027	358,511
	Total population size	347,520	70,694
	Total number of villages	493	47
	Villages surveyed (population size)	Ambatohambana (846) Ambatoharanana (480) Ambinanisahavolo (211) Ambohimarina (450) Seranantsara (46) Androfia (100) Sakalava (100)	Vohitromby II (1613) Ambatomasina (483) Mahadio (821)
Farming systems	Farming systems	Slash and burn agriculture in highlands; irrigated agriculture in lowlands	Slash and burn agriculture in highlands; irrigated agriculture in lowlands
	Subsistence crops	Rice, corn and cassava	Rice, corn and cassava
	Cash crops	Ginger, cloves, coffee. white beans and bananas	Cloves, coffee, white beans and bananas
	Percent of households who have agriculture as main source of income	99	99
	Percent of farmers who cultivate less than 2 ha of land	77	91
Farmer characteristics	Mean family size (± SE)	5.4 ± 2.1	5.6 ± 2.5
	% of families who do not produce enough food to feed their families during the entire year	75	70
	% of population that is under the national poverty line	72	89

Table 2
Actions taken by smallholder farmers to reduce the impact of cyclone Giovanna on their homes, agricultural production and families in the Ankeniheny Zahamena Corridor and Nosivolo, Madagascar. Numbers represent the percent of farmers who implemented a particular action.

Goal	Preventative actions	Percent of farmers
To protect homes	Secured roof	43
	Secured windows and doors	3
	Put up posts to support walls	6
To protect family members	Sought shelter (e.g., in a church or school)	18
	Moved family (children) to another region	13
	Ensured that the family had sufficient food reserves	37
To ensure food and water security	Stored food in a place where it would be protected from floods	32
	Stored clean water for use following the cyclone	70
To protect agricultural production	Stored rice seeds in a dry location to prevent damage from floods and rain	19
	Moved livestock to higher ground or safe location	22

3.2. Impacts of cyclone Giovanna on agriculture, housing, infrastructure and farmer livelihoods

A majority of farmers (87%) indicated that Giovanna was the strongest cyclone in the last decade and had significantly impacted their livelihoods. According to the farmers, Giovanna had a 'strong' impact on crop loss (81% of all farmers reported losing crops), flooding (59%), schools and churches (57%), houses (56%) and road infrastructure (36%; Table 3). Cyclone damage to infrastructure was significant: more than 80% of farmers suffered damage to their houses, such as collapsed or damaged roofs, or damaged walls, and 18% of farmers reported that their houses had been completely destroyed. Farmers indicated that the houses which were most damaged by the cyclone were those made of Ravenala and houses located in hill slopes or near rivers. Damage to public infrastructure was also significant: most local schools, churches and markets were closed for repair for one or more weeks following the cyclone. The direct impacts on livestock and injuries to people were considered less severe. The cyclone also affected the availability of non-timber forest product such as honey and wild yams that farmers regularly extract from forests, by destroying vegetation and making it difficult for farmers to access the forests.

Table 3
Farmer perceptions of the level of damage and impacts caused by cyclone Giovanna in the Ankeniheny Zahamena Corridor and Nosivolo, Madagascar. Numbers represent the % of farmers reporting a given level of damage. Damage levels are subjective categories identified by farmers, rather than quantitative damage levels.

Types of impacts	Levels of damage incurred			
	No damage	Minimal	Moderate	Strong
Flooding	12	4	25	59
Damage to houses	3	9	33	56
Damage to schools and churches	13	11	21	57
Damage to roads	13	13	39	36
Crop damage	1	1	18	81
Injury or death of livestock	27	18	32	24
Injury of people	95	3	2	1
Availability of non-timber forest products from forest (e.g., honey, wild yams)	27	18	32	24

Cyclone Giovanna had particularly negative impacts on agricultural production and household food security. Almost 90% of farmers indicated that their rice fields were damaged by the cyclone (Table 4). The level of damage was variable, with some farmers

Table 4
Farmer assessments of the impacts of cyclone Giovanna on agricultural production, food stores and household food security in the Ankeniheny Zahamena Corridor and Nosivolo, Madagascar.

Variable	Response	% of farmers
Percent of farmer's rice crop fields damaged by cyclone	None	5
	< 25%	10
	25–50%	21
	50–75%	22
	> 75%	38
Location of rice fields which were most affected by the cyclone[a]	Valley	22
	Floodplain	9
	Hill slope	20
	All	49
Percent of farmers whose stored grains were damaged by the cyclone (n=200)		70
Percent of stored grains that were damaged by the cyclone (n =140)	< 25%	24
	25–50%	20
	50–75%	18
	> 75%	39
Percent of farmers with insufficient food to feed their families following the cyclone (n=179)		89
Percent of months that households lacked sufficient food to feed their households following the cyclone (n=178)	2 months	3
	3–5 months	38
	> 6 months	47

[a] Percentages do not add to 100 for this question as farmers mentioned multiple locations as being affected.

Table 5
Impacts of cyclone Giovanna on water availability and health of smallholder farmers in Corridor and Nosivolo, Madagascar.

Impact		Percent of farmers
Lacked access clean drinking water after the cyclone (n=129)		35
Type of available water source for drinking and cooking, following the cyclone (n=132)	A public standpipe with tap	12
	A public standpipe without tap	20
	A standpipe with/ without a pump	7
	Well	10
	Rivers	36
	Lake or pond	5
	Other (stream, rainfall)	11
Suffered diseases in the last month following the cyclone (n=200)		66
Health problems reported following the cyclone (n=130)	Diarrhea	54
	Cholera	2
	Other (flu, cough, malaria)	45

reporting that they lost less than 25% of their crop, while others reported losses of more than 75%. The location of rice fields in the landscape appeared to have little impact on the damage sustained.

Table 6
Coping strategies used by smallholder farmers in Nosivolo and CAZ, Madagascar, to deal with damaged crops, increased food insecurity and income loss due to cyclone Giovanna.

Issue	Coping strategy used	Percent of farmers
Damaged agricultural lands (n=196)	Replanted fields	70
	Waited to replant in the next season	27
	Abandoned fields	3
	Changed the type of crops	1
Food insecurity (n=187)	Bought additional food	85
	Reduced food consumption of staple foods(quantity or frequency of meals)	82
	Harvested wild food	40
	Received food from relatives	16
	Received food from neighbors	10
	Received food aid from government and NGOs	5
Income loss and additional costs associated with cyclone damage (n=189)	Sent an adult household member to get an outside job	51
	Borrowed money from friends	11
	Made children work more on the farm	8
	Sent older children away to work	7
	Took boys out of school	3
	Took girls out of school	3
	Leased land to other farmers	1
	Took out a loan	1

Roughly half of the farmers also lost stored grains to the cyclone (Table 4). For many farmers the loss was significant: 39% of the farmers who had stored grains lost more than three quarters of their stored food supplies to the cyclone. As a result of crop damage and the loss of stored grains, 89% of farmers indicated that their household did not have sufficient food to meet their current needs. Thirty eight percent of the farmers indicated they lacked sufficient food for 3–5 months following the cyclone, while an additional 47% indicated they would lack food for > 6 months.

The cyclone also had significant impacts on the availability of clean drinking water and farmer health. Approximately three quarters of the farmers did not have access to a clean drinking water following the cyclone, as the rivers, streams and wells where they collect water had mud and debris. As a result, most waterborne diseases, such as diarrhea, were common in the month following the cyclone (Table 5).

3.3. Coping strategies used by smallholder farmers

Farmers coped with adverse impacts of cyclone Giovanna on agricultural production, food security and income loss/increased costs in several ways (Table 6). Most farmers (71%) replanted crops in the fields that had been damaged, however a subset of farmers (27%) decided not to replant until the next season and 3% of farmers abandoned their crop fields due to flooding and siltation. Restoring flooded croplands and replanting crops was time consuming: 49% of the farmers indicated that they would have to spend more than one month replanting fields that had been damaged by the cyclone.

Farmers coped with the food insecurity caused by the cyclone by reducing food consumption, buying additional food and receiving food aid from neighbors or relatives (Table 6). Only 5% received food aid from the government. In addition, more than

half of the farmers reported sending an adult household member to get a temporary outside job to generate income to buy food and pay for necessary expenses. Other, less common, strategies for increasing household income included borrowing money from friends and making children work more on the farm.

Almost all farmers had to rebuild or repair their homes following the cyclone. In most cases, farmers collected materials (timber, Raphia, Ravenala, etc.) directly from the forest to rebuild their homes, or bought these materials from other farmers who had collected these materials in the forest and had carts to transport the materials from the forest to the village. In addition, a subset of farmers had to buy additional materials (especially wood and nails, but, in a few cases, also tin roofs, cement, and concrete) to rebuild their homes. The total costs of local materials for rebuilding the houses varied across farmers, with an estimated mean of 50,000 $\pm$ 11,519 Ariary (or 25 $\pm$ 5.8 US dollars). Farmers paid for these costs by selling crops (35% of farmers), performing off-farm labor (25%), selling small livestock (24%), using savings (18%), or selling other assets (13%) such as radio sets or sewing machines. Less than 8% of farmers borrowed money or took out a loan to cover these costs. All farmers reported relying on their extended families and, to a lesser degree, on friends and neighbors (30%) to help them collect local materials and providing labor to rebuild their houses, with rebuilding taking anywhere from a couple of days (31% of farmers) to more than a month (28% of farmers) for those farmers who have houses made of cement or bricks. Only 5% of the farmers received any food, building materials or financial support from formal organizations.

Farmers identified several strategies which could have helped reduce the impacts of cyclone Giovanna on their livelihoods. These approaches included building sturdier houses (mentioned by 95% of farmers), storing more grains prior to the cyclone (84%), protecting livestock (76%) relocating to the shelter earlier (67%), moving temporarily to another location (49%) and selling stored crops prior to the cyclone (34%).

4. Discussion

4.1. Impacts of cyclones on livelihoods of smallholder farmers

Our study highlights the devastating impacts that cyclones can have on the livelihoods of smallholder farmers in Madagascar and the urgent need to help these farmers better prepare for and cope with these impacts. While previous studies in Madagascar have documented the overall damage (e.g., numbers of houses, roads and bridges destroyed and area of crops lost) and costs of cyclones at the national or regional scale [7], this is the first study to our knowledge to examine in detail how Malagasy smallholder farmers prepared for the cyclone, how their livelihoods were impacted, and how they coped with these impacts. Our study suggests that cyclones pose a significant challenge for Malagasy smallholder farmers, causing significant damage to crop fields, loss of stored grains, damage to houses, increased food insecurity, reduced access to clean water, and increased incidence of water-borne diseases. In addition to the immediate impacts, cyclones are likely to continue to affect smallholder farmers for months, possibly years, into the future, as the loss of agricultural productivity and associated decline in food security and income generation further exacerbate their already precarious living conditions. Studies of other cyclone-prone developing countries have similarly highlighted the impacts of cyclones in exacerbating rural poverty, stalling rural development, and amplifying the vulnerability of smallholder farmers who are already poor and vulnerable (e.g., [4,16,32]).

Malagasy smallholder farmers are vulnerable to cyclones and other extreme weather events for a variety of reasons. First, Malagasy smallholder farmers are extremely poor (with most living under the national poverty line of 468.800 Ariary (234 USD) per year), rely almost entirely on agriculture for their livelihoods, and suffer chronic food insecurity even in regular, non-cyclone years [23,51,53]. The regular 'lean' season in Madagascar occurs between October and March [28] and the majority of farmers lack sufficient food during this time. In CAZ and Nosivolo, smallholder farmers are food insecure for an average of 3.7 months per year [19]. Cyclones tend to hit during the peak of the lean season, further exacerbating food insecurity and extending the lean season by several months. When crops are damaged by strong cyclone winds and associated flooding, farmers are left both without sufficient food and without the means to generate income to buy food. Since farmers usually have little or no savings, they often fall in further hardship. These interlinkages between poverty, food insecurity and vulnerability to climate risks have also been documented elsewhere (e.g., [25,32]).

Malagasy smallholder farmers are also highly vulnerable because they lack access to extension and formal support systems which could help them better prepare for and cope with the impacts of cyclones. Like many remote rural regions in Madagascar, CAZ and Nosivolo receive little government support and are serviced by few organizations. Farmers in these regions rarely receive any technical support for agricultural production [19] or disaster relief following cyclones While other more accessible regions received emergency support such as food, building materials and essential supplies from both the national government and disaster relief organizations (e.g., CARE International and Catholic Relief Services) following cyclone Giovanna [7], farmers in CAZ and Nosivolo received no support in the month following the cyclone's devastation. This lack of formal support reflects the remote location and poor road infrastructure of the study sites, as well as the limited resources and capacity of the Malagasy government to respond to natural disasters. During the recent political crisis (2009–2014) in Madagascar, most donors froze their development aid to the country resulting in an estimated 600 million euros (824 million USD) loss [51]. As a result, the Malagasy government now has even less money available for disaster relief efforts [11].

4.2. Strategies for reducing impacts of cyclones on smallholder farmers

4.2.1. Reducing the vulnerability of smallholder farmers and enhancing resiliency

In Madagascar, reducing the impacts of cyclones on smallholder farmers will require addressing three key and interrelated issues. First, there is a need to reduce the inherent vulnerability of smallholder farmers by improving their living conditions, food security and access to basic services. This is a daunting challenge given high levels of poverty and food insecurity among farmers, limited government resources for addressing poverty and food security issues, poor road infrastructure, limited capacity and resources for disaster relief and adaptation efforts [7,23,53,54]. Major investments are urgently needed to improve health services, infrastructure, education, and housing, alleviate poverty, improve food security, provide extension services to farmers and promote the development of livelihood options that are resilient to climate change [5,37,53]. Studies of smallholder farmers elsewhere (e.g., [6,9,32]) have similarly highlighted the urgency of reducing the underlying vulnerability of smallholder farmers to climate change by tackling poverty and food insecurity, fostering resilience to climate change shocks, developing social safety nets and mainstreaming climate adaptation into rural development initiatives. In particular, the provision of agricultural extension services to farmers to help enhance agricultural productivity, diversify their income generating activities and encourage the adoption of

adaptation measures will be critical for reducing their vulnerability to cyclones and other climate risks [4].

4.2.2. Enhancing farmer preparedness for cyclones

Second, there is an urgent need to help smallholder farmers prepare for upcoming cyclones by providing them with more detailed, advance information about incoming cyclones, and about the precautionary measures they should take to minimize potential cyclone impacts. In Madagascar, the Meteorological Service is in charge of providing cyclone warnings to the national broadcasting company, who then announces this information to the public. While most of the smallholder farmers in our study sites heard about cyclone Giovanna from the National Broadcasting Service of Madagascar, the warning arrived only 1–2 days before the cyclone struck, giving them little time to prepare [24]. In addition, most farmers were unaware that this would be the strongest cyclone since 1994 to hit the eastern coast of Madagascar and did not expect significant levels of damage [38]. As a result, the level of preparation among farmers was low. Earlier and more detailed alerts are needed to convey the expected magnitude of upcoming cyclones and to provide specific instructions to farmers on how to best prepare. Improving access to better climate information is known to be an effective means of increasing awareness of climate risks and helping farmers make informed decisions about how to prepare for cyclones and other extreme weather events (e.g., [31,44]).

Additional training and outreach is also needed to help ensure farmers adequately prepare for cyclones and implement adaptation measures that help reduce their overall vulnerability to climate risks. Madagascar's National Strategy for Reducing Risks and Disasters [50] recommends that farmers prepare for cyclones by storing enough food and clean water for the duration and immediate aftermath of the cyclone, securing homes and other assets to minimize potential damage, and seeking refuge in secure buildings to prevent human injury and death, however many farmers did not follow these instructions and were therefore unprepared when cyclone Giovanna arrived. Finding ways of preventing damage to houses is a particular challenge. While many farmers secured their roofs in preparation for the cyclone, more than 80% still suffered significant damage to their homes. It is well known that concrete or brick houses are less likely to be damaged by cyclones, but few smallholder farmers are able to afford them. In addition, in focal group discussions farmers indicated that they prefer the traditionally Raphia and mud homes because although they are more likely to be damaged by cyclones, they can be easily repaired using local materials collected from the forest and therefore cost less to rebuild. Encouraging farmers to seek shelter in churches, schools and other sturdy building is also challenging, as farmers are reticent to leave their homes and move to shelters for fear of having their household possessions stolen while they are gone [41].

There are a number of other actions that could also help minimize potential impacts on smallholder livelihoods and farming systems. For example, farmers should ensure that any stored seeds or harvested crops are carefully protected from wind or flooding damage by storing them in waterproof bags or receptacles, and moving them out of the path of potential flooding. Most farmers store seeds in plastic bags on the floor of their homes, so simple actions such as ensuring the bags are waterproof and placing them high on the family table or storing seeds in waterproof containers could prevent unnecessary seed loss. Community granaries could be strategically located in less exposed areas to allow storing grains in safety. Farmers should also ensure irrigation channels and drainage ditches are well maintained to minimize flooding of crop fields, and, where necessary, dig additional ditches in anticipation of the cyclone to divert flood waters. Restoring riparian areas along rivers, reforesting upland slopes and enhancing vegetative complexity within field could also help reduce flooding from cyclones [21,35]. It is also critical to conserve the remaining forest areas in the agricultural landscapes, as forests serve a key safety nets for smallholder farmer's following cyclones, providing them with emergency food supplies and building materials for home reconstruction [19].

4.2.3. Creating formal safety nets for smallholder farmers

Finally, there is a need for formal safety nets (e.g., government programs, development organizations, disaster relief agencies, etc.) which can provide farmers with emergency food aid, credit or money for meeting their immediate food needs, materials for rebuilding homes, and seeds, tools and other agricultural inputs for replanting their crops. These formal safety nets should also provide access to clean water supplies immediately following the cyclone and help clean the stagnant water in wells following cyclones to avoid them serving as breeding grounds for mosquitoes and other disease-spreading insects [40]. Malagasy farmers currently rely almost exclusively on extended families and neighbors for support, but these informal networks are incapable of mitigating the substantial impacts of cyclones on local livelihoods. More formal and better financed disaster relief programs and institutions could significantly help reduce both the immediate and long-term effects of cyclones on local communities. Better access to agricultural extension services will also be key for improving farmer knowledge and use of adaptation strategies (such as improved management of soil and water resources, timing of crop planting, etc; [3,4,31]) that could help minimize the impacts of future cyclones on farming systems. Improving access to formal support networks and extension services is a necessary step for breaking the vicious cycle of poverty, food insecurity and vulnerability that currently entraps smallholder farmers [3,36].

5. Conclusions

Our study suggests that cyclones pose a tremendous challenge for Madagascar's large population of smallholder farmers. Cyclone Giovanna inflicted substantial damage to crops and homes, significantly increased food insecurity, and decreased availability of clean water to smallholder farmers. These impacts exacerbate the already very high levels of poverty and food insecurity among Malagasy smallholder farmers. While smallholder farmers have a wide number of coping strategies for dealing with the aftermath of cyclones, they still suffer significant impacts when cyclones hit and remain highly vulnerable to future extreme weather events. There is an urgent need for governments, donors, and development organizations to reduce the inherent vulnerability of Malagasy smallholder farmers to cyclones and other climate risks by improving early warning systems, helping farmers prepare for upcoming cyclones, creating formal safety nets to help farmers access food, water and other essential supplies following cyclones, and promoting the use of adaptation measures to enhance the resiliency of farming systems to future climate shocks. These actions are critical for not only for reducing smallholder vulnerability to cyclones and other climate shocks, but also for tackling the unacceptably high levels of food insecurity and poverty among Malagasy smallholder farmers.

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References

[1] J.N. Abramovitz, Averting unnatural disasters, in: L.R. Brown, C. Flavin, H. French, (eds.), State of the World 2001, A Worldwatch Institute Report on Progress Toward a Sustainable Society, New York, 2001, pp. 123–142.
[2] E. Alam, A.E. Collins, Cyclone disaster vulnerability and response experiences in coastal Bangladesh, Disasters 34 (2010) 931–954, http://dx.doi.org/10.1111/j.1467-7717.2010.01176.x.
[3] C.S. Bahinipati, Determinants of farm-level adaptation diversity to cyclone and flood: insights from a farm household-level survey in Eastern India, Water Policy 17 (2015) 742–761.
[4] C.S. Bahinipati, L. Venkatachalam, What drives farmers to adopt farm-level adaptation practices to climate extremes: Empirical evidence from Odisha, India, Int. J. Disaster Risk Reduct. 14 (2015) 347–356.
[5] C.B. Barrett, C.M. Moser, O.V. McHugh, J. Barison, Better technology, better plots or better farmers? Identifying changes in productivity and risk among Malagasy rice farmers, Am. J. Agric. Econ. 86 (2004) 869–889.
[6] G.D. Bhatta, P.K. Aggarawal, Coping with weather adversity and adaptation to climatic variability: a cross-country study of smallholder farmers in South, Asia Clim. Dev. 8 (2016) 145–157.
[7] BNGRC (National Office for Risk and Disaster Management). Bilans des dégâts suite aux passages du cyclone tropical intense" Giovanna ", de la tempête tropicale modérée "Irina" et de la ZCIT, 2012. Available at: ⟨http://www.bngrc.mg⟩ (accessed 12.06.14).
[8] M. Brockhaus, H. Djoudi, B. Locatelli, Envisioning the future and learning from the past: Adapting to a changing environment in northern Mali, Environ. Sci. Policy 25 (2013) 94–106, http://dx.doi.org/10.1016/j.envsci.2012.08.008.
[9] E. Bryan, T.T. Deressa, G.A. Gbetibouo, C. Ringler, Adaptation to climate change in Ethiopia and South Africa: options and constraints, Environ. Sci. Policy 12 (2009) 413–426.
[10] A. Candradijaya, C. Kusuma, Y. Syaukar, L. Syaufina, A. Faquih, Smallholder farm households' vulnerability and adaptation to climate-induced food insecurity, Br. J. Appl. Sci. Technol. 4 (2014) 4974.
[11] A. Clayton, Destructive Storms, Dormant Policies: The Impact of Cyclones on Food Security in Madagascar, The Africa Portal, Backgrounder 2012, No. 46, 2012. Available At: ⟨http://www.africaportal.org⟩ (accessed 9.7.13).
[12] S. Dercon, Income risk, coping strategies and safety nets, World Bank Res. Obs. 17 (2002) 141–166, http://dx.doi.org/10.1093/wbro/17.2.141.
[13] B. Dostie, S. Haggblade, J. Randriamamonjy, Seasonal poverty in Madagascar: magnitude and solutions, Food Policy 27 (2002) 493–518.
[14] S. Doocy, A. Dick, A. Daniels, T.D. Kirsch, The human impact of tropical cyclones: a historical review of events 1980–2009 and systematic literature review, PLoS Curr. Disasters (2013), http://dx.doi.org/10.1371/currents.dis.2664354.
[15] J.U. Ganzhorn, Cyclones over Madagascar: Fate or fortune, Ambio 24 (1995) 124–125.
[16] G.A. Gbetibouo, C. Ringler, Mapping South African farming sector vulnerability to climate change and variability: A subnational assessment. International Food Policy Research Institute (IFPRI) and Center for Environmental Economics and Policy in Africa (CEEPA), 2009.
[17] Government of Madagascar. Damage, Loss and Needs Assessment for Disaster Recovery and Reconstruction after the 2008 Cyclone Season in Madagascar. Government of Madagascar, 2008. Available at: ⟨http://www.3adi.org/tl_files/3ADIDocuments/Country%20information/Madagascar/Madagascar_gov_2008_recovery_plan.pdf⟩ (accessed 16.05.13).
[18] R. Gutro, Dangerous Tropical Cyclone Giovanna to Make Landfall in Madagascar. NASA's Goddard Space Flight Center, 2012. Available at: ⟨http://www.nasa.gov/mission_pages/hurricanes/archives/2012/h2012_Giovanna.html⟩ (accessed 20.03.13).
[19] C.A. Harvey, Z.L. Rakotobe, N.S. Rao, R. Dave, H. Razafimahatratra, H. Rabarijohn, et al., Extreme vulnerability of smallholder farmers to agricultural risks and climate change in Madagascar, Philos. Trans. R. Soc. 369 (2014) 20130089, http://dx.doi.org/10.1098/rstb.2013.0089.
[20] T.W. Hertel, S.D. Rosch, Climate change, agriculture and poverty. Policy Research Working (Paper 5468), The World Bank, Washington D.C, 2010.
[21] E. Holt-Gimenez, Measuring farmers' agroecological resistance to Hurricane Mitch, LEISA Mag. 17 (2001) 18–20.
[22] S.M. Hsiang, A.S. Jina, The causal effect of environmental catastrophe on long-run economic growth: evidence from 6700 cyclones. National Bureau of Economic Research, USA, 2014. Available at: ⟨http://www.nber.org/papers/w20352⟩ (accessed 03.12.14).
[23] Institut National de la Statistique de Madagascar (INSTAT), Enquêtes périodique auprès des ménages 2010, 2011, Antananarivo. Available at: ⟨www.instat.mg/pdf/epm_10.pdf⟩.
[24] IRIN, Madagascar: Cyclone Giovanna Struck with Little Warning, 2013. Available at: ⟨http://www.irinnews.org⟩ (accessed 9.07.13).
[25] P.M. Kelly, W.N. Adger, Theory and practice in assessing vulnerability to climate change and facilitating adaptation, Clim. Change 47 (2000) 325–352.
[26] A.F. Mavume, Climatology and landfall of tropical cyclones in the south-west Indian Ocean, West. Indian Ocean J. Mar. Sci. 8 (2009) 15–36.
[27] Météo-France, Tableau De définition Des Cyclones, 2008. ⟨http://www.meteo.fr/temps/domtom/La_Reunion/TGPR/PagesFixes/GUIDE/Guide AlerteCyclonique.html#tableaudanger⟩.
[28] Ministry of Agriculture, A Monography of Vatovavy Fito Vinany, Amoron'ny Mania, Vakinanakaratra, Ambatondrazaka regions, Ministry of Agriculture of Madagascar, 2004. Available at: ⟨www.agriculture.gov.mg⟩ (accessed 11.12.13).
[29] Ministry of Agriculture, Annuaire Agricole 2005–2008. Ministry of Agriculture of Madagascar, 2009, p. 112. Available at: ⟨http://www.agriculture.gov.mg⟩ (accessed 11.12.13).
[30] J.F. Morton, The impact of climate change on smallholder and subsistence agriculture, Proc. Natl. Acad. Sci. U.S.A. (2007) 10419680–10419685 http://dx.doi.org/10.1073_pnas0701855104.
[31] F. Mtambanengwe, P. Mapfumo, R. Chikowo, T. Chamboko, Climate change and variability: smallholder farming communities in Zimbabwe portray a varied understanding, Afr. Crop Sci. J. 20 (2012) 227–241.
[32] K. Mutabazi, S. Sieber, C. Maeda, K. Tscherning, Assessing the determinants of poverty and vulnerability of smallholder farmers in a changing climate: the case of Morogoro, Tanzania, Reg. Environ. Change 15 (2015) 1243–1258.
[33] D.J. Nash, K. Pribyl, J. Klein, G.H. Endfield, D.R. Kniveton, G.C.D. Adamson, Tropical cyclone activity over Madagascar during the late nineteenth century, Int. J. Climatol. 35 (2015) 3249–3261, http://dx.doi.org/10.1002/joc.4204.
[34] H. Osbahr, C. Twyman, W.N. Adger, D.S. Thomas, Effective livelihood adaptation to climate change disturbance: scale dimensions of practice in Mozambique, Geoforum 39 (2008) 1951–1964.
[35] M.A. Palmer, C.A. Reidy Liermann, C. Nilsson, M. Flörke, J. Alcamo, P.S. Lake, N. Bond, Climate change and the world's river basins: anticipating management options, Front. Ecol. Environ. 6 (2008) 81–89.
[36] M.M. Rahman, B. Klees, T. Sal-sabil, N.A. Rice Khan, Smallholder farms and climate change in Bangladesh: Thala of policy options, J. Indian Res. 2 (2014) 59–66.
[37] J.C. Randrianarisoa, B. Minten, Agricultural production, agricultural land and rural poverty in Madagascar. Cornell Food and Nutrition Program Working (Paper 112). Cornell University, New York, 2001. Doi: http://dx.doi.org/10.2139/ssrn.439101.
[38] N.N. Raonivelo, Early actions before and after the arrival of the cyclone, 2013. BGNRC. Available at: ⟨www.bngr.org⟩ (accessed 12.06.14).
[39] J. Ratsimbazafy, M.L. Gore, L.J. Rakotoniaina, Community policing in indigenous communities in Madagascar, in: K.N. Mahesh, R.N. Graeme (Eds.), Community Policing in Indigenous Communities, CRC Press, Fl, USA, 2011, pp. 31–40.
[40] Relief Analysis Wire, Madagascar Bracing for Post-Cyclone Disease Outbreak, 2012. Available at: ⟨http://www.reliefanalysis.com/2012/02/madagascar-bracing-for-post-cyclone.html⟩ (accessed 09.07.13).
[41] RFI, Madagascar: Les sinistres appelés à rejoindre de secours, 2015. Available at: ⟨http://www.rfi.fr/afrique/20150302-madagascar-sinistres-appeles-rejoindre-sites-hebergements-secours-antananrivo-deplaces-inondations⟩ (accessed 24.06.15).
[42] J.M. Shultz, J. Russell, Z. Espinel, Epidemiology of tropical cyclones: the dynamics of disaster, disease, and development, Epidemiol. Rev. 27 (2005) 21–35, http://dx.doi.org/10.1093/epirev/mxi011.
[43] E. Styger, E.C.M. Fernandes, H.M. Rakotondrasamasy, E. Rajaobelinirina, Degrading uplands in the rainforest region of Madagascar: fallow biomass, nutrient stocks, and soil nutrient availability, Agrofor. Syst. 77 (2009) 107–122, http://dx.doi.org/10.1007/s10457–009–9225-y.
[44] R.C. Stone, H. Meinke, Weather, climate and farmers: an overview, Meteorol. Appl. 13 (2006) 7–20.
[45] M. Tadross, L. Randriamarolaza, Z. Rabefitia, K.Y. Zheng, Climate change in Madagascar; recent past and future. World Bank, Washington, DC, 2008. Available at: ⟨www.csag.uct.ac.za/~mtadross/Madagascar%20Climat%20Report.pdf⟩ (accessed 20.3.14).
[46] The World Bank, Madagascar revue du secteur rural et environnemental. (Volume 1. Rapport) Principal, The World Bank, Washington D.C., 2013.
[47] The World Bank, Madagascar disaster risk reduction plan. Africa on the move. The World Bank, D.C. Washington, 2010. Available at: ⟨http://siteresources.worldbank.org/intafrica/Resources/final_story_green-growth-madagascar.pdf⟩ (accessed 4.6.15).
[48] The World Bank, Madagascar overview, 2015. Available at: ⟨http://www.worldbank.org/en/country/madagascar/overview⟩ (accessed 15.6.15).
[49] M. Nasir Uddin, W. Bokelmann, J.S. Entsminger, Factors affecting farmers' adaptation strategies to environmental degradation and climate change effects: a farm level study in Bangladesh, Climate 2 (2014) 223–241, http://dx.doi.org/10.3390/cli2040223.
[50] UNDP/CNS, Stratégie Nationale de Gestion des risques et catastrophes- Madagascar, 2010. Available at: ⟨http://humanitarianlibrary.org/sites/default/files/2013/07/SNGRC.pdf⟩ (accessed 24.6.15).
[51] UNHRC, Report of the Special Rapporteur on the right to food, Olivier De Schutter. Mission to Madagascar, 2011. Available at: ⟨http://www.srfood.org/images/stories/pdf/officialreports/20130304_madagascarfinal_en.pdf⟩ (accessed 11.12.13).
[52] World Food Programme (WFP), Fighting cyclones, flooding, and drought in Madagascar, 2011. Available at: ⟨http://www.wfp.org/logistics/blog/fightingcyclones-floods-and-drought-Madagascar⟩ (accessed 15.7.13).

[53] WFP and UNICEF, Rural Madagascar Comprehensive Food and Nutrition Security and Vulnerability Analysis, Antananarivo, 2011. Available at: ⟨www.wfp.org⟩.
[54] M. Zeller, C. Lapneu, B. Minten, E. Ralison, D. Randrianaivo, C. Randrianarisoa, Pathways of rural development in Madagascar: an empirical investigation of the critical triangle between environmental sustainability, economic growth and poverty alleviation, Q. J. Int. Agric. 2 (1999) 105–127.