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Forest ecosystem services for agricultural risk reduction: examining interactions within socio-ecological systems in Madagascar

by

Radhika Dave

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FOREST ECOSYSTEM SERVICES FOR AGRICULTURAL RISK REDUCTION: EXAMINING INTERACTIONS WITHIN SOCIO-ECOLOGICAL SYSTEMS IN MADAGASCAR

Radhika Dave

ABSTRACT

Natural ecosystems like forests, wetlands and coastal habitats are hypothesized to support disaster risk reduction by decreasing the exposure of communities to hazards such as floods, landslides and storm surge. Forest cover loss is thought to increase flood risk and is seen as a primary driver of soil erosion and consequent siltation of irrigation channels and agricultural fields. While there is a growing body of evidence in support of the role of ecosystem processes in providing these hazard mitigation services much of it is site specific, and gaps remain in our understanding of the specific contexts, type of hazards and scenarios in which forest ecosystems play this role. This study contributes new knowledge to this research gap by investigating the question of how smallholder farmers in Madagascar exposed to extreme weather hazards perceive the importance of tropical dry deciduous forests in regulating hazard impacts and supporting agricultural production. In doing so, this thesis first evaluates the evolving trajectories of change in system variables including various provisioning ecosystem services, biophysical, economic and governance indicators, and human wellbeing outcomes during Madagascar's recent history to provide context and identify patterns at the national scale. It then investigates the problem at the local, sub-catchment scale in a case study setting through household surveys, focus groups and key informant interviews in two communities with opposing forest cover trajectories in northwest Madagascar. This combined methodological approach allows for the linking of local vulnerability to wider system dynamics. The first set of findings demonstrates that the broader systems dynamics show signs of trade-off between increasing crop production, deteriorating natural environment and decreasing human wellbeing, which together with an evident decrease in the level of connectivity between key parameters reflect conditions associated with stagnation and poverty traps. Case study results show a vulnerable smallholder farming population, typically exposed to a set of six hazard impact types during extreme weather events. The type of hazards experienced influences the perception of whether or not forests provide hazard impact mitigation benefits and this is one of thesis' original contributions to knowledge. Another core finding confirms the importance of tropical dry forests to the lives of smallholder farmers through food and raw materials, and provides new insights on the positive view held by a majority of the participants of hazard mitigation services provided by forest fragments, while also finding that only the income generating services of forest based tourism and honey production predict participation in forest management. This study integrates two normally distinct areas of research – hazard mitigation and forest ecosystem services - to provide new insights on the relevance of forest cover and management to agricultural risk reduction in smallholder, forest-edge farm communities, contributing new knowledge with implications for both forest management and rural development policies.

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DECLARATION OF AUTHORSHIP

I, Radhika Dave, declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

Forest ecosystem services for agricultural risk reduction: examining interactions within socio-ecological systems in Madagascar.

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
5. I have acknowledged all main sources of help;
6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
7. Parts of this work have been published as:

   i. Dave, R., Tompkins, E.L., Schreckenberg, K. (2016). Forest ecosystem services derived by smallholder farmers in northwestern Madagascar: Storm hazard mitigation and participation in forest management. Forest Policy and Economics. DOI: 10.1016/j.forpol.2016.09.002

   ii. Dave, R., Tompkins, E.L., Schreckenberg, K. (2017). Do perceived hazard mitigation benefits of forests affect hazard experiences in dry forest landscapes? A case study in Madagascar. Agriculture, Environment and Ecosystems. [*Submitted*]

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Definitions and Abbreviations

CFM	Community forest management
CHIRPS	Climate Hazards' group Infrared Precipitation with Stations
CI	Conservation International
CRED	Centre for Research on the Epidemiology of Disasters
DEM	Digital Elevation Model
DFO	Dartmouth Flood Observatory
DRI	Disaster Risk Index
DRR	Disaster risk reduction
EbA	Ecosystem based adaptation
EKC	Environmental Kuznet's Curve
FAO	Food and Agricultural Organization
FIRMS	Fire Information for Resource Management Systems
GIS	Geographic Information Systems
GNI	Gross national income
IPBES	Intergovernmental Science-Policy Platform for Biodiversity and Ecosystem Services
KI	Key informants
MA	Millennium Ecosystem Assessment
MCA	Multi-criteria analysis
MODIS	Moderate Resolution Imaging Spectroradiometer
NEAP	National Environmental Action Plans
ODA	Overseas development assistance

PAR	Pressure and release
PCA	Principal component analysis
PRA	Participatory Rural Appraisal
SAR	Synthetic Aperture Radar
SDG	Sustainable Development Goals
SES	Socio-ecological system
TDF	Tropical deciduous forests
TMPA	TRMM Multisatellite Precipitation Analysis
TOA	Top of atmosphere
TRMM	Tropical Rainfall Measuring Mission
UNISDR	United Nations' International Strategy for Disaster Risk Reduction

Chapter 1: Introduction

1.1 Overview

Natural ecosystems, like forests, wetlands and coastal habitats are hypothesized to support disaster risk reduction by decreasing the exposure of communities to hazards such as floods, landslides and storm surge (Sudmeier-Rieux et al. 2006). While there is a growing body of evidence in support of the role of ecosystem processes in providing these regulating ecosystem services of hazard mitigation (see for example, Jones et al. 2012), much of it is site-specific, and gaps remain in our understanding of the specific contexts, magnitude of hazards and scenarios under which ecosystems play this role (Calder and Aylward 2006, Stürck et al. 2014). Whereas inland forests have been argued to reduce the frequency and magnitude of floods acting as protection forests for people (Alila et al. 2009), land cover change, particularly deforestation, has been hypothesized to increase flood risk in developing countries (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). Land use decisions such as the type and location of farms, urban or rural areas, and natural forests versus monoculture plantations can mediate the impacts of extreme weather hazards such as floods, landslides, erosion and sedimentation. These combine with heterogeneity in soil, vegetation and channel density to add a significant level of complexity in the interacting processes and prevent broad scale predictability (Lambin et al. 2003, Wisner et al. 2004, Wheater and Evans 2009, Thompson et al. 2011, Kundzewicz et al. 2013). Hence, the question of how forests contribute to mitigating hazard impacts at the landscape scale is far from straightforward and requires detailed examination of various interacting ecological, socio-economic and biophysical conditions and processes.

Nevertheless, understanding the role of forests in reducing hazard events through the provision of regulating ecosystem services is a critical component of integrating ecological sustainability with agricultural risk reduction and rural development given the projections of increasing extreme weather events, climate variability and change (IPCC 2012, 2013), increasing demand for food to feed a growing world population and overexploitation and degradation of ecosystems globally (MA 2005), combined with the persistence of poverty in many regions of the world and increasing inequality within society. Investigating, establishing and articulating the links between forest ecosystem services and agricultural risk reduction presents an opportunity for decision makers, especially in tropical developing countries where resources for development and forest management are often constrained, natural hazards and disasters undermine development progress, and where current development trajectories are displaying evident trade-offs between economic development and ecological sustainability (Rees 1992, Balmford and Bond 2005). The research presented here contributes to this knowledge gap by examining the role of natural forests in agricultural risk reduction for smallholder farmers exposed to extreme weather hazards and identifying how such forest benefits translate into support for forest management action. This study does so by adopting a combined methodological approach that allows for the linking of local vulnerability and interactions through case study analysis to wider socio-ecological system's dynamics. Extreme weather hazards can take several forms, for example, heavy downpours leading to floods, high winds, extreme heat and cold spells, and droughts. In this thesis, I explore the relationship between intense rainfall linked hazards, such as floods and soil erosion, and forest cover, building upon the forest hydrology literature and investigating the relationship using a case study approach. Furthermore, the case study region selected is not prone to droughts, while it does experience periodic heavy rainfall events (PGM-E and GOM 2013).

1.2 The case for Madagascar as the study focus

Madagascar is a compelling case for this problem because of its history of deforestation and forest management efforts (Jarosz 1993, Harper et al. 2007, Raik 2007), its primarily rain-fed agriculture based economy with over 65 % of the population directly involved in farming, most of which can be characterized as smallholder farming (Minten and Barrett 2008) and its frequent exposure to damaging cyclones (GOM and GFDRR 2008, Fitchett and Grab 2014). Additionally, it is a globally recognized biodiversity hotspot (Myers et al. 2000), which has led to over thirty years of foreign donor support for conservation, particularly of its iconic land animals and forests, evidenced in the recently expanded protected areas' network providing much of the remaining natural forests with some form of formal management, with conservation initiatives often tied to development goals (Kull 2014, Waeber et al. 2016).

Much of Madagascar's agricultural production is based upon smallholder farms particularly for staple food crops like rice and cassava (Harvey et al. 2014) with cash crops like vanilla and cloves grown in a few regions. The longstanding narrative regards agricultural expansion and practices, specifically slash and burn, as primarily responsible for the continued deforestation of formerly forested areas (Harper et al. 2007, Gorenflo et al. 2011). The high levels of deforestation have been linked to severe erosion, the formation of erosional gullies leading to loss of productive farmland and soil fertility (Philemon 1983, Bakoariniaina et al. 2006). At the same time, smallholder farmers, who are typically exposed to multiple weather hazards, rely heavily upon a mix of forest resources to cope with the impact of agricultural risks (Morton 2007, Dave et al. 2016, Rakotobe et al. 2016). Tropical dry deciduous forests provide numerous ecosystem services yet their contribution to agricultural livelihoods remains underexplored (Maass et al. 2005) with rapid degradation and loss of this biome evident in Madagascar, as in other regions of the world (Waeber et al. 2015).

An unending quest to halt or slow down forest loss in Madagascar and the simultaneous country-wide expansion of small scale community forest management areas over the last fifteen years leads to the question of how well forest ecosystem services including the less tangible regulating ecosystem services, are incorporated into the programs for integrated development and conservation.

Much attention is being paid to the carbon sequestration service provided by Madagascar's natural forests as a means of securing additional support for conservation and rural development, though with questionable rural development impacts (Grinand et al. 2013, Poudyal et al. 2016). Much less attention has been devoted to understanding how the presence of managed forests (under different forms of protection including community management) may influence experiences of rainfall-linked hazards faced by agricultural communities living around these areas, and how these experiences feedback into action to support forest management or not. This is a question that has implications not only for the decentralized forest management efforts being widely promoted in Madagascar (Horning Rabesahala 2004, Raik and Decker 2007, Rasolofoson et al. 2015) but also for wider system resilience and ecological sustainability.

1.3 Research Aim and Objectives

The aim of this research project is to contribute to the empirical understanding of the extreme weather hazard mitigation services derived from forests by vulnerable smallholder farmers in forest edge communities in Madagascar. In order to do so the project focuses on the following three research questions:

1. How can the conditions of and reciprocal interactions between key socio-ecological systems variables be characterised during the recent history of Madagascar?
2. Do extreme weather hazard experiences and consequent crop damages suffered by smallholder farmers in dry forest landscapes influence the perception of hazard mitigation benefits of forests?
3. How do deriving forest use benefits and perceiving hazard mitigation services from forests motivate participation of smallholder farmers in community forest management groups?

1.4 Thesis structure

This research is presented as a 'three - paper PhD' format. The research aim, objectives and justification are presented in this first chapter. The thesis that follows is divided into six sections: literature review, research design, three substantive chapters (the three scientific papers) and a final conclusions chapter. This section provides a brief summary of each of these sections.

1.4.1 Literature Review

Chapter two first discusses the definitions, commonalities and differences in the use of terms at the core of this thesis to provide a theoretical foundation: vulnerability, hazard impacts and risks, and ecosystem services. It then reviews the wider literature linking regulating ecosystem services to hazard reduction, particularly focusing on the role of forests in moderating flood events. Finally, it reviews forest cover change and deforestation trends globally and with a focus on Madagascar. It concludes with a discussion of research gaps that are relevant to the aim of this project.

1.4.2 Research Design

Chapter 3 presents the overarching research design and includes a brief discussion of the rationale of adopting an interdisciplinary, mixed methods approach. It presents the underlying conceptual foundation for this thesis provided by the application of a combined socio-ecological systems dynamics and ecosystem services approach. It introduces the methods used to assess the evolution of the broader socio-ecological system such as time series analyses and the social research methods used in this research, namely those of household surveys, focus group discussions, key informant interviews and participatory mapping exercises. However, Chapter 3 provides a methodological overview; with details of the technical aspects of the various methods used reserved for the substantive chapters themselves to ensure a more logical flow.

1.4.3 Substantive Chapters

Chapters four, five and six each present the research results and comprise three stand-alone journal articles, one of which is published (Chapter 6), one is in review (Chapter 5) and one is near submission (Chapter 4).

Chapter 4 describes the evolution of the broader socio-ecological system at the national and district scale in Madagascar during the recent historical past and evaluates the conditions of and interconnectedness between key system parameters. These parameters include provisioning ecosystem services such as crop and livestock production, regulating services represented by forest cover, economic growth (or lack thereof), governance and biophysical system drivers and human wellbeing outcomes observed (Question 1). It provides a context for the analysis in the later chapters and a background to understanding the socio-ecological systems dynamics at varying scales.

Chapter 5, the first of two chapters drawing upon the case study data from two *fokontany* in northwest Madagascar, uses data from household questionnaire surveys (N=240) and focus group discussions to, i) identify extreme weather impacts upon smallholder farmers from 2000 - 2015 and assesses how socioeconomic and geographic factors influence these experiences, and ii) evaluate how farmers' hazard experiences influence local perception of forest regulatory services, specifically flood control and moderating the flow of excessive sediments and debris flow onto farmlands (Question 2).

Chapter 6, draws upon the case study research to i) assess the importance of the dry forest ecosystems in the lives of the smallholder farmers through the identification of the broad suite of forest ecosystem services, including hazard mitigation derived by study participants and, ii) identifies whether deriving forest use benefits and perceiving hazard mitigation benefits of forests motivates participation in community forest management groups (Question 3).

Each of these three substantive chapters includes a discussion of relevant literature, methods used, results and discussion of the overarching findings and implications within Madagascar as well as for other parts of the world.

1.4.4 Conclusions

Chapter 7 summarizes the conclusions of this study, discusses its novel contributions to knowledge, outlines its limitations and presents thoughts for future research.

Chapter 2: Literature Review

2.1 Introduction

This chapter provides a broad overview of the literature within the different disciplinary areas upon which this thesis is based. It consists of three overarching sections. The first focuses on an overview of key distinctions between the terms risks, natural hazards and disasters. The concept of vulnerability, which threads through this thesis, its roots and traditions in political ecology, ecological resilience and natural hazards, is also examined in this section, with relevance to socio-ecological systems. The second section presents recent literature arguing the case for ecosystem-based approaches for risk reduction and situates the aim of this thesis within this emerging paradigm. Subsequently, the scientific understanding of the mechanisms through which forests are thought to regulate flood hazards and the methods used to evaluate this relationship are reviewed and methodological gaps highlighted. The third section provides an overview of the characteristics of global land cover change focusing specifically on deforestation, and the trends and drivers of these changes in Madagascar. The final section presents the methodological and knowledge gaps emerging from this review which are then addressed in this study.

2.2 Hazards, Risk and Vulnerability

2.2.1 Hazards and Risk

Hazards can be described as an extreme physical event that is a chance phenomenon capable of causing harm (Merz et al. 2010a). Examples of extreme weather related hazards include floods, droughts, storms and cyclones. While disasters are many a times equated to extreme weather events such as heavy rainfall, coastal storms and cyclones, disasters and hazard are not one and the same (Few 2003, Wisner et al. 2004). Disasters are the combination of a hazard event acting as a trigger on an already vulnerable population to put life and property at risk – they are in a sense “the consequences of development failures” (Schipper and Pelling 2006: 22). According to the Centre for Research on the Epidemiology of Disasters (CRED), a disaster is “a situation or event that overwhelms local capacity, requiring assistance from outside; is an unforeseen or sudden event causing great damage and human suffering" (Guha-Sapir et al. 2013: 7). The United Nations' International Strategy for Disaster Risk Reduction (UNISDR) has a similar definition but goes on to add that disasters are usually defined as a "combination of the hazard event, the conditions of vulnerability and insufficient capacity to respond to and cope with potential negative circumstances" (UNISDR 2009). Disasters occur only when people are involved and are the "interface between an extreme physical event and a vulnerable human population" (O'Keefe et al. 1976: 566).

Risk is defined variously as a "chance event, an uncertainty of outcomes, actions and events, a probability of an adverse outcome, or as expected losses" (Aven and Renn 2009: 1-2). Wisner et al. (2004) define risk as a function of the hazard and the varying vulnerability of people to that specific hazard. Aven and Renn (2009) examine two definitions of risk where risk is expressed as an event and its consequence to something of human value and uncertainties associated with the outcome of the event. These definitions are essentially one and the same and express risk as the uncertainty associated with the consequence of an event on either human life or property and other elements valued by people (ibid: page 2). In considering socio-ecological systems exposed to hazards such as floods, uncertainty associated with hazard impacts is often times captured by the term "vulnerability" as seen in Wisner et al. (2004). Vulnerability has several overlapping definitions and antecedent tradition (Adger 2006) which are reviewed in the following section. Wisner et al. (2004) provide a progression of the underlying vulnerability of a system from "root causes", such as limited access to power, resources and institutions, to dynamic pressures, that together with "unsafe conditions", combine with a hazard event to produce a risk of a disaster. For the purposes of this thesis, risk is taken as the uncertainty associated with the outcomes of and severity of a specific hazard event, in relation to something people value (Aven and Renn 2009), for example, the farmland, soil fertility, crops.

Floods, mudslides, erosion gullies and debris flows triggered by excessive rainfall, cyclones and storm surges are examples of hydro-meteorological hazards, which depending upon the characteristics of the population or area affected can turn into disasters. In this sense, the classification used by CRED (Fig 2.1) is at odds with this distinction between hazards and disasters. Nevertheless, it is a useful representation of the various types of hazards that are linked to disasters.

Hydro-Meteorological Hazards	
Hydrological	Floods
	General Floods
	Flash Floods
	Coastal Storm Surge
	Mass Movement (Wet)
	Landslides
	Rockfall
	Avalanche
	Subsidence
Meteorological	Storms
	Tropical Cyclone
	Local storms
Climatological	Extreme Temperatures
	Droughts
	Wildfire

Table 2.1 – Types of hydro-meteorological hazards which can lead to disasters (adapted from Guha-Sapir et al. 2013).

2.2.2 Vulnerability

Much of the literature on vulnerability can be seen through two lenses: The first is vulnerability as the outcome of a disaster - as a function of exposure and sensitivity to hazards and the capacity of the system to adapt, as in the context of vulnerability to climate change (IPCC 2013). The second is vulnerability as a social condition (Adger 2006) in terms of the political, economic and geographic processes operating which influence how a system reacts to hazards (Cutter et al. 2003). It is used to denote both the susceptibility of a system to an external stressor or hazard, which contributes to its disaster risk, and to the outcome of a disaster event that makes one group or section of society, or region more vulnerable (Adger 2006). For example, Kron (2005) describes vulnerability as the "lack of resistance to damaging/destructive forces" (p. 61), denoting vulnerability as the state of being for the system under consideration. In the climate change arena, "vulnerability is defined as the degree to which a system is susceptible to and unable to cope with adverse effects" (Adger 2006: 269).

In simple terms, vulnerability to environmental hazards can be explained as the "potential for loss" (Cutter et al. 2003). However, decades of research in at times disparate traditions of knowledge (Wisner et al. 2004, Adger 2006) have established that vulnerability is a combination of social vulnerability and biophysical risk arising from the proximity to the hazard. An individual, state or even country's specific condition, such as social status, wealth, real income, community relations, political realities, influences the consequences of the natural hazard or another stressor experienced (Cutter et al. 2003). The antecedents of vulnerability are traced to the entitlements and hazards' literature by Adger (2006). The entitlements approach, developed by Amartya Sen (1982) to explain the underlying cause of famines focuses on an individual or group's ownership and exchange capacity to get access to food. Adger (2006) summarizes the link between vulnerability emerging from the entitlements approach as "*vulnerability of livelihoods to shocks occurs when people have insufficient real income or wealth and there is a breakdown in other previously held endowments*" (p. 270).

Frameworks like the sustainable livelihoods framework based upon the sustainable livelihoods approach (Chambers and Conway 1992, Carney 1999) share similarities with and build upon the entitlement framework contributed to the vulnerability literature. The sustainable livelihoods framework (SLF), while including "natural capital" to indicate natural resources that support livelihood generation, does not consider feedbacks between these elements and human wellbeing. Figure 2.1 shows a pictorial representation of the SLF with the five asset categories that poor, rural households depend upon for income generation, the external vulnerability context and the mediating social, political and institutional factors that mediate both the experience of vulnerability, the access to the assets and eventually to improved livelihood strategies.

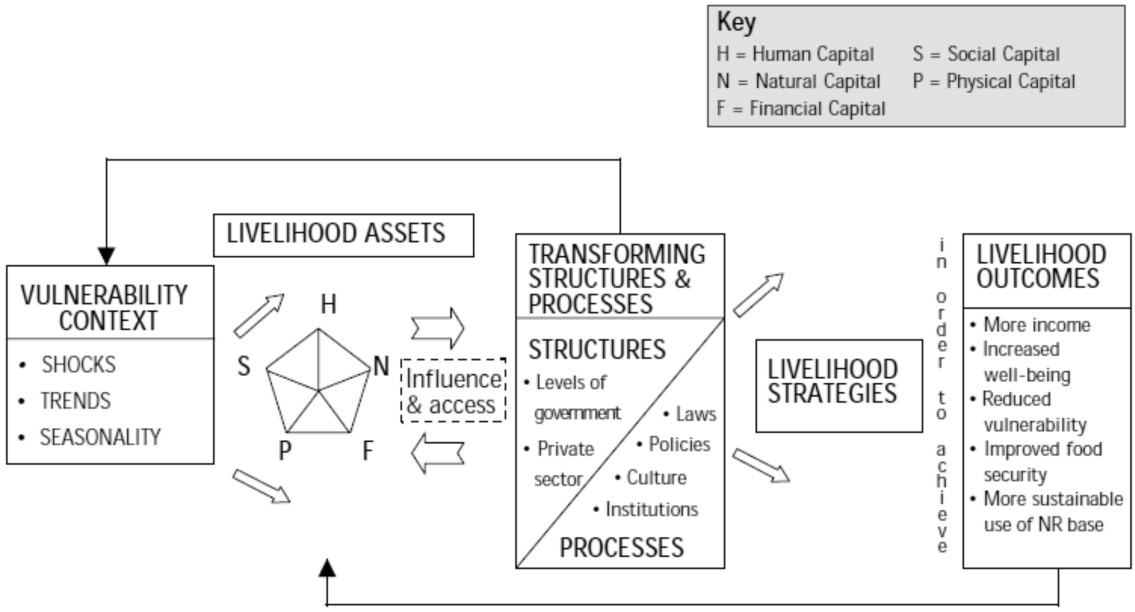

Figure 2.1 - The sustainable livelihoods framework (Carney 1999, Farrington et al. 1999)

Vulnerability also draws upon the work of Gilbert White (1945) on flood disasters and damages in the United States. The definition and conceptualization of vulnerability rising from the natural hazards literature, which has its roots in the flood damage and disasters work, integrates social and physical factors. This allows for a system that could influence an individual's susceptibility and exposure to a physical hazard and lead to differential vulnerabilities based upon a combination of physical stressors and geographic, social and institutional factors (Burton et al. 1968, Adger 2006). According to Wisner et al. (2004), vulnerability can be explained by looking at processes such as economic and geographical marginalization leading to political marginalization and disempowerment of groups of people who are then increasingly vulnerable to hazard events (page 52). However, these research traditions do not allow for an explicit integration of the ecological parameters that support ecosystem functions and thereby human societies.

Conceptual models that help integrate the variety of external shocks, processes and conditions that influence a complex socio-ecological system include the pressure and release (PAR) and access models (Wisner et al. 2004). More recent frameworks such as the DROP model for disaster resilience of place (Cutter et al. 2008) and a modified vulnerability assessment framework for coupled human-ecological systems (Turner et al. 2003) build upon these approaches and acknowledge the linkages between social and ecological variables. For example, Cutter et al. (2008) in explaining the assumptions of their DROP model acknowledge the inherent interconnectedness of natural systems, social systems and the built environment, going so far as saying "…a degraded environment provides less protection from hazards (p. 602). However, the DROP model fails to clearly articulate a space for analysing the impacts of land use change such as deforestation and hazards such as floods on the risk faced by rural agricultural livelihoods.

2.2.2.1 Socio-ecological systems and vulnerability

The systems view of the environment highlights the synergistic feedback between organisms and their environment that is the foundation for ecosystem function and structure (Berkes and Folke 1992). Evolutionary processes wherein organisms continue to evolve with and adapt to their physical environment are integral to continuity (ibid.). By acknowledging that people are part of and interacting with their natural ecosystems, the systems perspective leads to the foundation of the socio-ecological systems' paradigm. Complex socio-ecological systems are defined as systems within which humans and ecological components are co-evolving, interdependent and adapting in response to changes in the other (Norgaard 1987, Berkes and Folke 1992). To ensure sustainability of the human system, sustainability of the natural system is necessary (Costanza et al. 2007). Complex socio-ecological systems are essentially coupled – human environment systems with interactions and feedbacks between natural and human components including human institutions, that are reciprocal, reinforcing and have multi-scalar effects (Young et al. 2006, Liu et al. 2007). Vulnerability of complex socio-ecological systems thus needs to consider the impacts of hazards on the integrated socioeconomic, ecological and political system allowing for feedbacks and reciprocal responses.

Consider the three distinct theoretical and research paradigms to which Eakin and Luers (2006) trace the evolution of vulnerability: the risk-hazard paradigm, political economy and political ecology frameworks and ecological resilience. The risk - hazard paradigm builds upon the research on natural hazards in geography (White 1945, Burton et al. 1968) and is focused on the impacts of biophysical risks by seeking to answer the question "to what are we vulnerable, what might be the expected consequences and when and where these impacts may occur" (Eakin and Luers 2006 p. 369). The political economy lens focuses on the political, social and economic factors that influence who or what is vulnerable and the differential nature of this vulnerability. These frameworks investigate how vulnerable individuals or systems cope with the impacts of external stressors and/or adapt to future ones (ibid: 370). An example of this perspective is the work on entitlements and capabilities by Amartya Sen (Sen 1982). While political economy does not emphasize the role of ecological processes and biophysical phenomena in influencing vulnerability, political ecology argues for equal weight to be given to both ecological and social processes (Eakin and Luers 2006). Political ecology, by including a consideration of ecological components of the broader system, allows for an analysis of the vulnerability of the complex socio-ecological system as a whole.

Ecological resilience, defined as the capacity of a system to absorb disturbance and reorganize while maintaining its essential structure, function, feedbacks and identity (Walker et al. 2004) (Holling 1973), takes this integration one step closer. It draws upon resilience theory to view "vulnerability as a dynamic property of a socio-ecological system in which people are in constant interaction with the biophysical environment" (page 371, Eakin and Luers 2006). Ecological resilience enables researchers to focus on understanding processes of change and identify thresholds and underlying processes that allow natural systems to absorb disturbances (ibid: 372). More recently, the concept of development resilience as a framework through which to understand the feedbacks and mechanisms that link the natural system to the socioeconomic has been proposed as a means of developing more effective poverty alleviation strategies (Barrett and Constas 2014). Viewing human development needs and interventions through a resilience lens allows for a multi-disciplinary explanation of the interrelated dynamics of exposure to risk, human well-being and ecological processes (ibid:14625). While recognizing this wealth of research and cross-fertilization of different research paradigms that have influenced vulnerability, this thesis adopts a political ecology lens to assess the overarching research aim of understanding how forests and natural ecosystems influence agricultural risk reduction.

2.3 Risk reduction and ecosystem functions

Disaster risk reduction (DRR) is defined by the United Nations Office for Disaster Risk Reduction (UNISDR) as the "systematic development and implementation of policies to reduce vulnerabilities, hazards and the unfolding of a disaster" (Mercer 2010: 248). The main components of DRR are prevention, preparedness and mitigation (Schipper and Pelling 2006). By its definition and core objectives, disaster risk reduction has much in common with vulnerability (Djalante et al. 2012). Compared to short-term emergency relief and post-disaster reconstruction, DRR with its focus on prevention and addressing underlying drivers of risk has traditionally received less consistent attention and resources (ibid). The Hyogo Framework for Action signed in 2005 and operational over a ten year period was an international framework agreed upon by 168 countries to reduce the social, economic and environmental damages from disasters at both the national and community level (Djalante et al. 2012). In order to make countries more "resilient" to disasters, the framework set out five priorities for action for countries to recognize and make DRR a priority, increase awareness of risk and ability to take action, reduce risks and improve preparedness.

Given the global perception of increasing hydro-meteorological hazards and ensuing disasters (for example, Di Baldassarre et al. 2010), and the fact that few countries reached their Hyogo Framework targets (Djalante et al. 2012), the Sendai Framework for Disaster Risk Reduction was agreed upon in 2015 for a fifteen year period (Renaud et al. 2016). This framework makes an explicit reference to preserving ecosystem functions that support risk reduction as part of one of the overarching objectives of investing in disaster risk reduction and resilience. There is thus a renewal of interest in understanding the influence of natural ecosystems in supporting hazard mitigation and reducing exposure to hazards, and over the long term supporting adaptation to climate change impacts (Sudmeier-Rieux et al. 2006, McIvor 2012).

The next section considers this issue through an examination of the literature surrounding the role of natural ecosystems in DRR.

2.3.1 Ecosystem based approaches to DRR

There exist a broad suite of actions and projects aimed at mitigating disaster risk and helping communities adapt to the impacts of climate variability and change (McGray et al. 2007). These range from hard infrastructure projects such as dams and embankments to control floods, to "building institutional capacity" for managing slow onset risks and disasters. Over the last five to six years, calls for considering the role of ecosystem-based approaches have grown louder, though the evidence base for performance of such approaches (against for example that of infrastructure) is not strong. There are increasing efforts to collate and add to the body of evidence in support of this concept (e.g. Munroe et al. 2012).

The concept of "ecosystem based adaptation" (EbA) finds its formal conceptualization and definition in the report of the Second Ad Hoc Technical Expert Group on Biodiversity and Climate Change to the Convention on Biological Diversity (CBD 2009). The definition was further refined during negotiations at the UNFCCC COP in 2009. The working definition now commonly used is: "EbA is the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people adapt to the adverse effects of climate change" (Colls et al. 2009: 1). The concept therefore argues for the conservation, sustainable management and restoration of well-functioning ecosystem types (ibid.). Similar efforts to elucidate the role of ecosystems in disaster risk management are also increasingly available (Sudmeier-Rieux et al. 2006, Renaud et al. 2013). These strategies are premised upon the role of functioning ecosystems in regulating ecosystem processes such as the quality and quantity of water flow, sediment accretion and wave attenuation by coastal vegetation, and regional climate regulation by forests, amongst others. While it is often assumed that such regulating services are provided consistently, they vary across time and space, are dependent upon the health of the natural system and have thresholds driven by several factors (Koch et al. 2009).

The following section examines the rationale underpinning ecosystem approaches to extreme weather related risk reduction, and provides examples of the mechanisms through which these are hypothesized to work.

2.3.2 Mechanisms and examples for ecosystem-based approaches to DRR

Ecosystem services, defined as the benefits people get from nature, underpin most aspects of human wellbeing as the Millennium Ecosystem Assessment and many other studies have demonstrated (MA 2005, Vira et al. 2012). Ecosystem-based approaches to reducing extreme weather hazard impacts and disaster risks depend upon the provision of hazard mitigation, such as flood control, through ecosystem processes and functions. This approach is often promoted as a "no-regrets", more cost-effective and participatory option for reducing hazards and disaster risk compared to hard infrastructure projects (Colls et al. 2009, Jones et al. 2012). This thesis will consider a suite of extreme weather impacts on agricultural production, including flooding, erosional gullies and excessive sedimentation. The goal of this section is to provide a review of ecosystem types, specifically forests, and functions that are hypothesized to reduce these hazard impacts. To do so the following section first presents an overview of flood risk and management, and then focuses on the relationships between forests and floods as an example.

2.3.2.1 Flood risk and management

Floods are seen in many parts of the world as a “known risk” because of their repetitive nature (Wisner et al. 2004). Flood risk can be defined as a function of the hazard (for example an extreme rainfall event or a tropical storm) and the vulnerability of the population, which create “potential for casualty, damage destruction or other forms of loss” (Wisner et al. 2004, page 50). Floodplains are known to be some of the most fertile farming areas, and in many countries of the world, people have engaged in complex trade-offs between coping with floods and using their benefits (ibid.). Traditional flood management approaches have relied heavily upon controlling floods through structural measures such as dams and dykes, and have been utilised in various forms and at various scales for several thousands of years (Kundzewicz 2002). However, flood control measures are not always infallible and many disasters have arisen from structural failures (Wisner et al. 2004). For instance, in addition to being built to inadequate standards at times, dams can shift the floodwater problem elsewhere (ibid.). This is evident from the examples of dams that flood inhabited areas (as is the case with the controversial Narmada Dam in India or China’s Three Gorges Dam) or that route floodwaters through inhabited or ecologically sensitive areas (for example, India’s Farakka Barrage leads to the diversion of the Ganges’ peak flow through densely populated Bangladesh) (ibid.). In addition, flood control measures may instil a false sense of security in people and provide incentives to build in flood prone areas (Wisner et al. 2004). Agricultural land management practices, such as those seen in the United Kingdom since the 1950s, have also contributed to river channelization, increased surface run-off and the routing of rainfall to points downstream at rates faster than those that would have occurred under “natural” conditions of stream flow, generating floods in areas where previously flooding was not a common occurrence (O'Connell et al. 2007). Significantly, several wealthy countries have witnessed damaging floods, despite having longstanding investment in preventive structures (De Moel et al. 2009). Hurricane Katrina, which hit the Gulf coast of the United States in 2005 and led to floods because of levees breaching, was the most expensive single disaster costing over 147 billion USD. Flood related damages have cost European countries over 100 billion Euros over the period of 1986-2006 (De Moel et al. 2009). Flood management through control measures such as river training, the use of embankments, dams, levees, and reservoirs, while serving a purpose, can be expensive to maintain, involve uncertainty (breaks, damages, inadequate design standards) and absolute protection was seen as unsustainable (Schanze 2006). This realization has influenced policy makers in many countries, particularly in Europe, to develop a different approach focused more on managing the risk from floods.

Reflecting this shift within research and policy from flood “control” per se to risk management, flood risk management has emerged as an approach that includes not only the hazard (floods), but also the damage that occurs because of exposure and the vulnerability of affected elements (Merz et al. 2010b). Flood risk management can be defined as the “continuous and integrated analysis, assessment and mitigation of flood risk by society” (Merz et al. 2010a citing Schanze 2006: 510). It includes approaches such as improved land use zoning to avoid costly economic activities in flood prone areas, early warning systems, insurance programs and integrated watershed management (Kundzewicz 2002). Watershed management involves reducing impermeable surfaces to allow for more rainfall to infiltrate the soil, soil conservation and land use practices that minimize runoff and erosion such as contour ploughing, terrace planting and vegetation management (ibid.). In this respect, watershed management can be seen as an ecosystem based approach to reducing flood risk and integrating ecosystem services in meeting the demand for for flood mitigation within land use management (Stürck et al. 2014). Flood risk management is now formally enshrined in the European Union’s Flood Directive, adopted in 2007, and requiring all EU countries to produce flood risk management plans by 2015 (De Moel et al. 2009). However, in much of the developing world, the emphasis remains on flood control measures, predominantly those derived from engineered solutions.

Flood risk is also defined as “damage that occurs or will be exceeded with a certain probability in a certain time period” (Merz et al. 2010b, p. 1697). Another similar definition is given by De Moel et al. (2009) based upon the Kron (2005) definition, which states that flood risk can be seen as a function of the probability of the hazard, the values at risk (life, property, food production, etc.) and the vulnerability of these values/elements. This is similar to Wisner et al. (2004)'s approach of defining risk as product of hazard and vulnerability. This vulnerability, according to the authors, is driven by social and political processes underlying society, and influences the ability of affected individuals or communities to deal with flood hazards. However, by identifying specific "values" or elements that are at risk, Kron 2005 provides a starting point to quantify impacts from floods. O'Connell et al. (2007) on the other hand, define flood risk as derived from the combination of the probability that a critical peak discharge is exceeded (which they define as "flood hazard") and the consequent economic damage (page 97). In general, most studies view flood risk as a function of specific hazard events, the exposed elements (Kron's "values") and the vulnerability of these elements (the lack of ability to withstand these hazards) (Kron 2005).

In summary, flood risk can be represented by the following relationship (Kundzewicz et al. 2013):

Flood Risk = Flood Probability x Exposure x Vulnerability

De Moel et al. (2009) substitute "coping capacity" for vulnerability to avoid the at times confusing perceptions of the definition of vulnerability. However, these terms are not interchangeable, and vulnerability is often defined as consisting of exposure and sensitivity to an environmental change or hazard, and the capacity to adapt to these changes or cope with these hazards (Adger 2006).

2.3.2.2 Ecosystem-based approaches to reducing hydro-meteorological hazards

Ecosystem-based approaches are seen as a complement to more conventional infrastructure based techniques, such as building flood control dykes and sea walls. An example of a hybrid flood risk management project is the San Francisco South Bay Salt Pond Restoration Project that aims to convert 15,100 acres of former commercial salt ponds at the south end of San Francisco Bay to a mix of tidal marsh, mudflat and other wetland habitats. The incorporation of wetland restoration into this flood control project is anticipated to reduce the size of the levees needed to protect property inland from the wetlands, and reduce the costs of levees from 12 million USD to 7 million per mile[1].

Other examples of ecosystem-based approaches include the restoration and protection of mangroves along the Red River in Vietnam to reduce the impact of coastal waves and storm surges on property and lives (Hoang Tri et al. 1998) and the use of oyster reefs to reduce the amount of wave energy reaching shorelines. Mangroves, sea-grass beds and coral reefs act to attenuate wave action and reduce storm surge (Spalding et al. 2013). Several projects set up around Southeast Asia after the 2004 tsunami are premised on this ecosystem relationship to hazard mitigation. Current estimates for storm surge reduction in mangroves estimate anywhere from 5 cm to 50 cm water level reduction per kilometre width of mangrove forest (McIvor 2012). However, factors like species, density of forests, and local geology will also influence this service. Such gaps in understanding and knowledge about the influence and interaction of several factors on ecosystem service delivery make it difficult to ascribe hazard mitigation benefit using simple rule of thumb (Gedan et al. 2011).

Forests are hypothesized to reduce flood frequency and severity, according to a study conducted using data from fifty developing countries (Bradshaw et al. 2007), but there remain significant debates in the literature on this relationship (Calder and Aylward 2006). Deep rooted trees and shrubs reduce the risks of shallow landslides on slopes by providing cohesive strength to shallow soil mantles and facilitating drainage, and permanent conversion of mountain forests to croplands or pasture can increase the probability of landslides (Sidle et al. 2006). However, while the connection between forests and water regulation is well known, the specific relationships between controlling factors is not fully understood (Eisenbies et al. 2007). The biophysical role of forests in reducing flooding is particularly subject to debate arising from the complexity of establishing conclusive evidence in the field (Bathurst et al. 2011). The influence of forests and alternatively that of forest cover loss on flooding and flood risk is examined in detail next.

[1] San Francisco South Bay Salt Pond Restoration Project, Accessed December 2013: http://www.southbayrestoration.org/

2.3.3 Forests and Flood Regulation

A complex set of interacting biophysical processes and geomorphic characteristics affect the ability of forests to regulate flooding within catchments (Chomitz and Kumari 1998, Andréassian 2004, Calder and Aylward 2006). Floods occur when the ground is saturated and rivers overflow their banks. Factors influencing total water yield from a catchment and peak discharge include the presence or absence of vegetation, type of forest tree species, land use types (forests, pasture, agricultural use, urbanization), presence or absence of current or old forest roads, which can lead to soil compaction and increase the density of stream channels leading to increases in flooding, the type of soil, depth of soil, catchment elevation, steepness and distance from coasts (Bruijnzeel 2004, Bathurst et al. 2011, Ford et al. 2011). Several other processes within a catchment influence flood occurrence. These include the flow rate and the timing of peak flows, as well as changes in the channel forms and obstruction of river channels by processes such as sedimentation (Calder and Aylward 2006). In addition, it is thought that an important additional factor is the nature of land use after clearing and the manner of forest clearing, that affect flood frequency and magnitude through soil compaction due to roads built to facilitate logging, etc. (Andréassian 2004, Bruijnzeel 2004, Kuraś et al. 2012). The naturally high variation in hydrological processes is a function also of the geological foundations of different catchments, which influences groundwater infiltration and reserves (Bruijnzeel 2004, DeFries and Eshleman 2004).

2.3.3.1 Specific mechanisms through which forests regulate floods

The "Sponge" Effect

The sponge effect refers to the ability of forest and understory vegetation, litter and soil to act as a sponge in absorbing water from rainfall and gradually releasing it to streams and river channels (Bruijnzeel 2004). This effect arises due to various characteristics – soil under forests is thought to be more porous, roots and understory litter and vegetation also absorb water. For instance, under mature forests approximate 80-95% of rainfall infiltrates the soil. However, this effect will be variable based upon the type of soil substrate. The type of species of trees also influences water usage, groundwater table and surface flow (Jost et al. 2012). Tree roots influence soil moisture, the depth of ground water table and thus rainfall runoff dynamics. For example in Austria, a study to assess the differences in rainfall – runoff response between hill slopes planted with Norway spruce trees, *Picea abies,* and those with European beech, *Fagus sylvatica*, found that beech has mature roots at greater depths and thus displays less overland excess water flow after heavy rains, in comparison to the hill slope planted with Norway spruce under which the water table is shallower (Jost et al. 2012).

Evapotranspiration – soil water deficit

Trees can mitigate peak discharge flow under intense rainfall by maintaining soil moisture deficit through evapotranspiration for days or weeks, resulting in increased soil infiltration potential and water storage capacity (Eisenbies et al. 2007). This process increases the soil moisture deficit between rainfall events allowing more water to be absorbed during extended periods of rainfall, a factor also referred to as antecedent soil moisture levels (ibid.). This increase in soil moisture deficit contributes to a decrease in the risk of development of surface flows and thus a decrease in the risk of flooding and soil erosion (Cochard 2013). Hence, immediately after forest clearing most studies find an increase in water yield and stream flow at the local scale (Bruijnzeel 2004) due to a disruption of the process of evapotranspiration.

Canopy interception capacity

Trees also capture rainwater in their canopy delaying or preventing some of the water from reaching the ground, for example, during storm events upto 1.5 mm of water may be stored in the canopy of dense coniferous forests compared with 0.5 mm in pasture or farmland (Eisenbies et al. 2007).

2.3.3.2 Role of forests and forest clearance in catchment response to rainfall events

The general consensus with regard to the flood hazard reduction role of forests emerging from the literature points to the following:

1. Forests in small catchments under low to moderate, more frequent rainfall events do play a role in mitigating floods through the mechanisms mentioned above (Bruijnzeel 2004, Eisenbies et al. 2007, Bathurst et al. 2011).
2. For small catchment sizes, there is evidence that differences in forest cover affects rainfall with return periods of less than 10 years (Bathurst et al. 2011)

3. This role is hypothesized to taper off as the size of the rainfall event increases, and is particularly hard to detect for larger catchments.
4. Nevertheless, complex interactions between the biophysical factors influencing flood mitigation, the type of data analysis conducted as well as the focus on flood magnitude rather than frequency (Alila et al. 2009) are seen as some of the contributing factors to the perceived lack of agreement between the two sides.

Several field research studies have contributed to the current scientific understanding over the extent and nature of the role of forests, and that of forest clearance and conversion in influencing water flow, including flood peaks (Andréassian 2004, Tran et al. 2010, Bathurst et al. 2011, Jost et al. 2012). While the effect is variable and is influenced by the above mentioned factors, in general, forestry practices, including deforestation, increase storm flow volumes and decreases time to peak flow for small catchment sizes and for small to moderate rainfall events; but as the size of the rainfall event increases this effect is less evident, especially for larger catchments (Wilk et al. 2001, Bruijnzeel 2004, Laurance 2007, Bathurst et al. 2011). However, there are some unresolved issues with these studies - despite several studies it remains unclear exactly what is considered a “large” event. To a great extent the size of the event and its significance in terms of flood generation capacity will differ from catchment to catchment (Bathurst et al. 2011). A second reason for this ambiguity is possibly the short study periods for experiments that have informed much of the scientific literature on forests and floods in comparison to the much longer reoccurrence periods for larger events (e.g. a 100 year flood – a flood event that has a 1% probability of occurring in any given year).

Bathurst et al. (2011) test the third point above - the hypothesis that forest cover and change do not have a significant effect on flood generation in large catchments by analysing data from four South and Central American countries. They include variable catchment sizes in their experimental sites ranging from .03 to 1400 sq km. The sites have both temperate and tropical rainforests, and are affected by extremes of rainfall from hurricanes, as well as snowmelt in the case of Argentina. The study finds that peak discharge increases by a mean of 32% between pre and post logging conditions for their site in Chile. The authors also show that the change in forest cover should be at least 20-

30% for an effect in peak discharge to be measured (ibid). However, this does not account for the fact that different parts of the catchment forest may influence peak discharge differently.

From these and other experimental studies conducted in several regions of the world, evidence points to large flood events (those with a long reoccurrence period) responding differently to vegetation changes than small events (Lewis et al. 2010). Most experimental studies aimed at understanding the response of catchment hydrological processes to changes in vegetation have used the paired catchment method (DeFries and Eshleman 2004, Brown et al. 2005). Several reviews of these studies have been conducted over the years including Bosch and Hewlett (1982), Hornbeck et al. (1993) and Brown et al. 2005. Most authors point to limitations of the approach while maintaining its utility. Other methods that have been used to assess the role of forest and forest clearance include mechanistic models, and metric and parametric watershed simulation models that are driven by empirical data (Eisenbies et al. 2007). The next section provides an overview of the use of paired catchment approach to assess the impact of changes in vegetation cover on water yield and flood peaks, and highlights specific areas of contention and debate emerging from the literature.

2.3.4 Paired Catchment Studies – Historical perspective on the relationship between forests and floods

A paired catchment experimental approach, in which a treatment and control watershed that are close together and similar are used to assess the impact of forest harvesting on flow peaks, has been the dominant method used by forest hydrologists for more than a hundred years (Bosch and Hewlett 1982, Andréassian 2004, DeFries and Eshleman 2004, Bathurst et al. 2011). In this method, two catchments that are similar in terms of slope, aspect, soil, climate, vegetation and are adjacent or close to each other are observed during a calibration phase, after which one is treated with harvesting or afforestation (of pasture land) while the other is kept as control (Brown et al. 2005). The data collected from such studies on total annual water yield is usually analysed by deriving a regression equation based on the volume discharges in the two catchments during the calibration period and fitting it on the treatment catchment to predict the difference in water yield post treatment which is attributed to changes in vegetation (Brown et al. 2005). Most studies using this approach study the impact of vegetation regrowth, deforestation, afforestation (growing trees on pasture or grasslands) and conversion from one type of forest to another (Brown et al. 2005). Several authors point to various limitations of this approach. Brown et al. (2005) consider the limitations arising from the fact that a majority of studies looking at the impact of vegetation regrowth have a short dataset of three to five years to consider the impact of harvest on water yield. However, these short time periods may not capture the natural variability in rainfall that would influence the relationship between changes in vegetation and water yield. In addition, the influence of soil compaction and roads in the immediate aftermath of forest clearing can increase overland flow for a short period of time and influence the calculations of total water yield after vegetation change (Bruijnzeel 2004).

Paired catchment experiments are expensive, usually conducted on very small plots and are not representative of the highly variable conditions found in real world conditions; and thus it is difficult to extrapolate results to larger catchments and different environmental conditions (DeFries and Eshleman 2004). While it is seen that a change in forest cover of at least 20% must take place to detect significant changes in water yield at small scales, at the watershed scale it becomes important to be able to detect changes when less than 20% of the watershed is treated (Brown et al. 2005, Eisenbies et al. 2007). However, at the watershed scale several attributes like unsynchronised flood peaks for different stream flows add to the inability to detect a significant flood peak after deforestation at the larger scale (Bruijnzeel 2004).

Data from paired catchment studies have also been analysed using different methods leading to opposing conclusions on the role of forests in preventing floods (Bruijnzeel 2004, Alila et al. 2009, Bathurst et al. 2011). For example, Alila et al. (2009) point to improper use of ANOVA and ANCOVA on data from paired catchment studies resulting in misleading and incorrect estimates of changes in the magnitude of floods (page 14). The same authors also argue that small changes in magnitude of water yield can lead to significant changes in the frequency of flood events after forest clearing and that “changes in frequency are an essential but ignored dimension of the relation between forest harvesting and floods” (Page 14). Wissmar et al. (2004) looked at seven watersheds in Northwest United States and compared discharge rate in the pre-settlement (full forest) condition with that in 1991 and 1998 for rural and urban watersheds. Flood frequency curves showed higher discharge rate in 1991 and 1998 time periods in comparison to the pre settlement discharge rate. Floods with less frequent recurrence intervals (10 and 25 year events) during pre-settlement conditions were seen to occur more frequently post urbanization (every 2 and 10 years) indicating a change in flow regime post harvesting (Wissmar et al. 2004). These results support the argument by Alila et al. (2009) that their approach of using a frequency paired analysis on data from paired watershed experiments (rather than the more widely used simple regression model) shows a reduction in the recurrence period of large flood events post forest clearing. However, the debate of impacts on large events of vegetation clearance rages on with different scientists challenging these and other results based upon methodological assumptions, data and analytical conclusions (Lewis et al. 2010).

2.3.5 Methodological conclusions

As is evident from literature scale plays an important role in assessing the impact of forest clearance on flood events (Bruijnzeel 2004, Calder and Aylward 2006). The effect of deforestation on small catchments and small flood magnitudes is more evident from the paired catchment studies and this effect is difficult to extrapolate to larger scales and larger flood events (Andréassian 2004, DeFries and Eshleman 2004). However, ambiguity remains on the magnitude of floods that are considered large in this context (Alila et al. 2009). Furthermore, most of the existing experimental studies with the exception of a few (Bruijnzeel 1990) are from temperate, developed countries rather than from the tropics where the majority of the high biodiversity forests remain. Thus, broader methods that can be used to examine these relationships in such settings need to be examined for relevance.

If risk is taken as a function of hazard and vulnerability (Wisner et al. 2004), natural ecosystems are hypothesized to both reduce the exposure to hazards such as coastal storm surges, wave action and wind, inland floods and droughts, and secondly support the ability of affected individuals and populations to cope with the impact of hazards (Pérez et al. 2010, McIvor 2012, Stürck et al. 2014). It can be argued that maintaining natural ecosystems, for example, inter-tidal mangrove forests, not only provides reduces exposure to storm surges, but also maintains important fisheries thereby supporting livelihoods and reducing certain aspects of long term vulnerability, and addressing an important but often overlooked element of disaster risk management (Merz et al. 2010a).

This thesis analyses these hypothesized relationships within the context of smallholder farmers and the agricultural risks experienced. It does so by taking a broader methodological approach, eschewing a biophysical assessment of forest – flood linkages. Instead the thesis uses social research methods in a case study focus to capture the whole range of possible agricultural risks triggered by extreme weather hazards and examines how these hazard impacts influence land use decisions in the wider sub-catchment.

The next section presents a review of trends and drivers of deforestation in the tropics as part of the justification for the urgency of expanding our understanding of regulating ecosystem services that support human wellbeing and can thus motivate more sustainable management of forests.

2.4 Land Cover Change – trends and drivers of deforestation in the tropics and in Madagascar

Forests are critical to the Earth's global carbon cycle as well as the global hydrological cycle. Tropical forests are centres of global biodiversity hotspots (Myers et al. 2000) and support various direct human needs through provisioning services such as fuelwood, food, fibre, medicines and timber, provide a multitude of cultural services and hold special significance for many indigenous peoples (MA 2005, Wright 2010). One of the greatest pressures on the remaining tropical forests is that from land use and cover change caused by a variety of factors (Hansen et al. 2008). Land cover change refers to the transformation of the biophysical attributes of the surface of the earth including the conversion of forests to other uses (Lambin et al. 2001). Combined with changes in land use by people, it is one of the major drivers affecting the planet's ecosystem functions, goods and services (Lambin et al. 2003), by transforming forests and other wetlands into agricultural land, urban centres or industrial complexes. This section focuses on the trends in and drivers of a specific type of land cover change – deforestation.

Forests are characterised as land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ (FAO 2015). Deforestation occurs when forested land is converted to another land use/cover type or when the tree canopy cover density per unit area (ha) is reduced to below a minimum percentage threshold (10%) (Lepers et al. 2005). It is relevant here because deforestation and the consequent loss in vegetation and changes to soil characteristics have a bearing upon local flooding, soil erosion and loss of fertility, sedimentation of irrigation channels and can cause erosional gullies to form over time in combination with heavy rainfall events (Bakoariniaina et al. 2006, Blöschl et al. 2007).

2.4.1 Deforestation trends

Humans have modified forest cover all over the world for millennia, starting with the use of fire to limit the expansion of forests and clear ground for agriculture. Even areas with dense forests in the present age bear evidence of previous forest clearing, for example, the west coast of southern Central America (Wright 2010). According to Wright (2010), deforestation since 1700 is characterized by two and in some regions, three phases. The first of these was a fairly gradual conversion of forest to cropland starting in 1700; the second phase was marked by a faster rate of deforestation starting in about 1800 in South Asia and late 1800s in Africa, and finally a few regions demonstrate a third phase of decelerating forest to agriculture conversion rate, such as in Mexico and Central America in the 1950s and in South Asia in 1980s (Wright 2010). This latter phase is seen as part of the “forest transition” process, which begins with conversion of forests to mainly cropland to feed the increasing demand for food and fibre and eventually leads to forest regeneration when agricultural fields are abandoned, urbanization becomes a greater source of employment or reforestation is actively implemented (Rudel et al. 2005). This transition is similar to the Environmental Kuznets Curve (Stern et al. 1996). Notwithstanding this forest transition, deforestation in the humid tropics is still occurring at a faster rate than regeneration or reforestation (Wright 2005, FAO. 2010). It is evident that the tropics have experienced great amounts of deforestation with particularly higher rates witnessed in the 1980s and 1990s (ibid.). Tropical South America shows the largest amount of deforestation followed by insular Southeast Asia (Barbier and Burgess 2001), however, continental Southeast Asia has the highest rate of deforestation at 1.6 % per annum, followed by Mexico and Central America at 1.5% per annum (ibid.).

It is important to acknowledge that there is some lack of consensus on precise trends in global humid forest areas (Grainger 2008, Hansen et al. 2008) though contested

(Steininger et al. 2008). The main reason for this is the considerable variation between countries and over time in the quality of forest inventory data collected and submitted to the United Nations' Food and Agricultural Organization (FAO) (Grainger 2008) . One of the primary means of estimating changes in forest cover are based upon national forest inventory statistics provided by countries to the FAO, which since 1946 has compiled comprehensive forest resource assessments every 5-10 years (FAO. 2010). Criticism of the FAO database is related to issues with the working definition of forests and the quality and dates of the national inventories (Barbier and Burgess 2001, Rudel et al. 2005, Wright 2005, Malhi et al. 2013). The FAO defines land as "all forests" if greater than 10% of the area is covered by crowns of trees higher than 5 m (Wright 2005). 'Closed forests' are defined as land where greater than 40% is covered by tree crowns and without any continuous grass cover (Wright 2005). Both the criteria for classifying land as "forests" (10% canopy cover invariably includes large swathes of savannah and cleared land) and the variable quality of national land cover change inventories between countries and over time mean that accurate estimates of deforestation trends have been challenging (Wright 2010). In an effort to improve this situation, for the Global Forest Assessment Report of 2010, the FAO used Landsat imagery for the first time as a complementary means of gathering time series data. These results were updated in 2010 and provide the latest assessment of deforestation and forest cover change at the global, regional and climatic zone scale (D'Annunzio 2014).

Over the last few decades the rapid advancements in satellite based monitoring has allowed for progressively improved methods to capture deforestation both at the continental scale, such as that caused by clear cutting large swathes of forests for agri-industrial uses or at the much finer resolution of 30 meters provided by Landsat imagery which is able to capture forest degradation and deforestation caused by smallholder clearings (Wright 2005, Hansen and Loveland 2012). Limitations with satellite based monitoring of forest cover change include those imposed by the instrument's spatial resolution, which can produce inaccurate measurements of forest clearing areas and rates, especially where the patterns of deforestation are complex (Lambin 1999, Tucker and Townshend 2000, Yoshikawa and Sanga-Ngoie 2011). However, the short revisiting time, and spectral resolution such as in the Moderate Resolution Imaging Spectroradiometer (MODIS) (with daily, 8-day, 16-day temporal resolution and 36 spectral bands) have encouraged the use of spatially coarser imagery on deforestation studies (data acquired by MODIS are delivered at three spatial resolutions: 250, 500 and 1000m) (Portillo-Quintero et al. 2013, Pacheco et al. 2014).

In the case of medium resolution satellite instruments, such as Landsat which yields images that can monitor at a finer spatial resolution (with pixel size ranging from 15 to 60m) the limitations are closely related to temporal resolution (16 days), which is in many cases insufficient to produce image composites that are able to overcome scene contamination by clouds (Wright 2005, Hansen et al. 2008).

In order to reconcile spatial and spectral resolution issues presented by the different type of satellite imagery, Hansen et al. (2008) in their assessment of forest cover change in the humid tropics between 2000-2005 used moderate spatial resolution datasets (MODIS) in combination with the finer resolution Landsat data to present a multi-sensor remote sensing approach. The authors use the MODIS data to first identify areas likely to see forest loss and to stratify the humid tropics into regions of low, medium and high likelihood of deforestation and then use Landsat imagery to identify forest loss in a random stratified sample of 183 plots within these regions (ibid).

Based upon these various methods, several studies estimate the latest trends in deforestation showing marked regional variations. These are presented below with a specific focus on Africa and Madagascar.

2.4.1.1 Trends in deforestation: Regional variations

While the issues of validity and reliability of data submitted to the FAO are well known, in recent years several studies have attempted to bring definite clarity to global trends in deforestation. By some estimates 54,000 to 64,000 km^2 of tropical forest is deforested each year (Wright 2010, Malhi et al. 2013). According to Hansen et al. (2008), the rate of clearing in tropical humid forest biomes during 2000 – 2005 was similar to that in the 1990s at 1.39% of the total humid tropical forest biome. The authors estimate that 55% of the total clearing occurs in only 6% of the forest biome, indicating the concentration of deforestation in some regions (ibid). Brazil dominates these estimates with forest loss representing over 47.8% of total biome clearing, followed by Indonesia at 12.8%. According to this analysis the entire continent of Africa contributes 5.4 % of the total humid forest area lost. This estimate is about one third of the FAO's Forest Assessment

Report estimate for Africa (Hansen et al. 2008, FAO. 2010). Another figure estimates that Africa contributes about 11% to the global gross deforestation (Malhi et al. 2013). Mayaux et al. (2013) estimate that Africa (including Madagascar) lost 5900 km^2 of forest in the period 1990-2000 and a further 2900 km^2 in the period 2000-2010. However, these differences in proportion of African deforestation notwithstanding, the common conclusion in most studies is that Latin America and Asia are at the forefront of tropical humid forest deforestation, with Africa having witnessed less threat to the Congo Basin rainforest than the Brazilian Amazon or the Indonesian forests (these three: the rainforests of the Amazon, the Congo Basin and Indonesia constitute the three largest remaining swathes of rainforest in the world) (Barbier and Burgess 2001, Wright 2005, Hansen et al. 2008, Malhi et al. 2013).

While Africa's humid tropical forest deforestation is lower than that of Asia or South America at the continental scale, within the continent marked variations can be observed in the rates of deforestation between West Africa, Madagascar and Central Africa. According to Mayaux et al. (2013), despite a reduction in both the rate and total area deforested in 2000-2010 from the 1990-2000 levels for Central and West Africa, Madagascar still shows high levels of deforestation. While the bulk of the forested area lost was in Central Africa (50-60% of deforested area) the rate of deforestation in Central Africa is lower than that for West Africa or Madagascar (ibid.). Madagascar's deforestation trends have been monitored since the 1960s when the first spatial map of vegetation types was created using aerial photographs from 1950s and 60s (Green and Sussman 1990, Vågen 2006). Despite some level of debate in the literature on the extent of Madagascar's original forest cover before human arrival (Kull 2000, Harper et al. 2007), the trends in forest loss over the last six decades are well recognized. These include a 43% loss in area of humid forest between 1950 and 2000, and a sharp increase in the annual deforestation rate from about 0.3% in 1950s to 1.7% in the 1970-1990 (Harper et al. 2007). The average deforestation for the island in the 1990 – 2000 period was about 0.9% (ibid), but according to Mayaux et al. (2013), the deforestation rate for Madagascar between 1990 – 2000 was 1.69% decreasing to 0.97% in the period 2000-2010.

The variations between continents and within regions in the scale of deforestation can be explained by various factors, including population density, agricultural expansion, infrastructure expansion, urban centres and other drivers. These factors are classified as proximate or underlying causes of deforestation, according to the widely used conceptual framing provided by (Geist and Lambin 2002) and explored in greater detail in the next section.

2.4.2 Drivers of deforestation

A large body of literature exists on the various drivers of land cover change and deforestation in particular, approaching the issue from distinct disciplinary lenses. These are studies focused on particular regions (for example, Serneels and Lambin 2001, Agarwal et al. 2005, Nackoney et al. 2014), global syntheses based upon case studies (Geist and Lambin 2001, Malhi et al. 2013) or publications putting forward theoretical models and frameworks to understand the various drivers of deforestation (for example, Shandra 2007). The purpose here is to acknowledge the breadth and depth of studies and present a brief overview of the main factors seen to drive deforestation without going into a critique of various perspectives and theories used to explain drivers of deforestation.

Earlier studies of causes of deforestation have predominantly held a neo-Malthusian perspective on human population rise being the leading factor driving rapid and recent deforestation (for example, Allen and Barnes 1985, Rudel and Roper 1997). This perspective on deforestation states that population growth is one of the major factors increasing deforestation; however, it is acknowledged that limited economic opportunities in poorer countries and negative national debt balances both work in conjunction with population growth to expand shifting cultivation and large scale export crop production or timber harvest (Rudel and Roper 1997). Other related hypotheses, such as the environmental Kuznets Curve (EKC) derive from the modernization theory, according to which initial stages of economic development lead to increasing deforestation before this forest loss levels off as economies mature (Shandra 2007), similar to the term “forest transition” coined by Alexander Mather (Rudel et al. 2005). However, over the last twenty years or so, studies on drivers of deforestation in the tropics have increasingly emphasized the complex interacting forces underlying deforestation even as the proximate causes in some regions have shifted from subsistence agriculture to the expansion of agri-industrial production for export (Lambin et al. 2001, Rudel et al. 2009, DeFries et al. 2010).

As noted by multiple studies of land cover change neither poverty nor population growth can be seen as causes of deforestation operating in isolation, but rather deforestation is driven by a combination of underlying processes and immediate pressures that lead to land use and cover change (Lambin et al. 2001, Agarwal et al. 2005, Hansen et al. 2008). Most of these factors can be classified as proximate causes such as shifting agriculture, clear cutting for commercial agriculture, demographic changes, mining, energy production and urbanization. Underlying drivers include those associated with globalization such as export-import trade and dynamics between countries (referred to as the "world-system" drivers by Shandra (2007)), land use policies driven by economic interests, and property rights' conflicts (Serneels and Lambin 2001, Mayaux et al. 2013). Literature overwhelmingly points to agriculture being the largest historical and contemporary driver of deforestation globally, whether mechanized agriculture or smallholder farms. Gibbs et al. (2010) analyse Landsat images and report that across the tropics over 55% of new agricultural land came from previously undisturbed forests and another 28% came from disturbed forests during the 1980s and 1990s. This is to be expected as food production, whether for global demand or domestic, is the primary human need derived from land and demand for agricultural products globally is expected to increase by 50% by 2050 (Gibbs et al. 2010).

Proximate drivers and underlying causes of deforestation based upon Lambin et al. (2001) and Hosonuma et al. (2012):

1. Proximate Drivers

- Swidden agriculture (slash and burn)
- Agricultural expansion
- Pasture expansion
- Urbanization
- Roads (e.g. logging roads, highways)

2. Underlying Drivers

- Economic: road and market development, market access/integration, and other economic structures
- Agricultural policies and land use policies
- Demographic change (population growth and in-migration)
- Land tenure and absence of clear titles (e.g. van Vliet et al. 2012)

While there are many drivers of forest loss in common between Asia, South America and Africa, some authors point to a case of "African exception" when it comes to dominant factors influencing deforestation (Fisher 2010, Rudel 2013). More specifically Fisher (2010) emphasizes that the pattern of deforestation in Africa does not conform to the analyses by DeFries et al. (2010) who report that modern day tropical deforestation is driven by urban population growth and export oriented timber and agriculture. According to Fisher (2010), deforestation in African countries is still driven to a large part by the expansion of shifting agriculture into forests and the extraction of wood, for fuel, timber and charcoal consumption domestically. Rudel (2013) states that for the most part Sub Saharan African countries have demonstrated lower rates of deforestation than other regions of the world and posit that this is in part driven by limited presence of industrial scale agriculture, the relative absence of large government settlement schemes and possibly for some oil and mineral rich countries, tax receipts from royalties.

In most African nations, shifting cultivation and charcoal production have remained the dominant proximate causes of deforestation. This pattern of cause and effect can be said to hold true for Madagascar as well (Zaehringer et al. 2016). Shifting cultivation practices in recent decades are frequently associated with low economic development, large scale poverty, high rural unemployment and high rural population (Bhattarai and Hammig 2001). Shifting agriculture (known locally as *tavy*) is important in areas where farmers have no access to credit, face high transaction costs and where it is preserved as risk mitigating strategy (van Vliet et al. 2012). Unlike Asia, Latin America and parts of continental Africa, Madagascar has seen an increase in shifting agriculture in forested regions (ibid.) for many of the reasons already stated (Harvey et al. 2014). However, deforestation here as elsewhere has a long historical record with forest use decisions made in colonial and pre-colonial times still reverberating today. For instance, under French colonial rule, Madagascar saw rapid deforestation despite low population growth and a ban on shifting cultivation (Jarosz 1993). Local underlying factors influencing deforestation in Madagascar include the lack of tenure and clear property rights (van Vliet et al. 2012). In addition, fires as sign of protest in the dry southern and southwest of the country have also contributed to forest destruction (Kull 2000). More recently since the coup d'etat of 2009, illegal logging for rosewood by cartels and clearing of forests for mining and settlement have escalated the level of forest degradation and loss.

Madagascar's remaining tropical humid forests are found mainly in the north-south corridor in the country's eastern highlands. This spatial pattern can be attributed to both the rugged topography and extensive agriculture and mining (Mayaux et al. 2013). This linear corridor of remaining forests is also where the bulk of the conservation investments in terms of protected areas' designation are to be found. While it is evident that these forests provide multiple ecosystem services including biodiversity, water quality and carbon sequestration (Wendland et al. 2010), there is minimal understanding of the flood mitigation value of the protected forests within these watersheds and the loss of these services that can be attributed to forest loss. Additionally, dry deciduous forests found in west Madagascar have traditionally been overlooked in terms of significant management and resources, yet these forests harbour high levels of biodiversity and are a source of livelihood benefits for many Malagasy (Elmqvist et al. 2007). Only one study considers the contribution of forests to flood mitigation for agricultural households in Madagascar (Kramer et al. 1997), a country that experiences floods on a seasonal basis and one where infrastructure expenditure on disaster risk reduction is at a minimum.

2.5 Concluding remarks and research gaps

A review of the literature on forests and their role in mitigating hazards triggered by extreme weather events such as floods indicates that while there are some areas of consensus, there remain gaps in knowledge of the specific mitigation value of many tropical forests. This can be attributed to the site-specificity of hydrological processes, the variety of influencing biophysical factors and their complex interactions (Wilk et al. 2001, Bruijnzeel 2004). While some studies show that inland forests have the potential to reduce the frequency and magnitude of small to medium floods (Bradshaw et al. 2007, Alila et al. 2009, Locatelli and Vignola 2009), others find no significant correlation between forest cover and floods, especially those associated with extreme rainfall (Tran et al. 2010). This lack of consensus is driven by the site specificity of the exact relationship between deforestation and changes in flood frequency and magnitude, with several biophysical elements influencing this relationship (Bruijnzeel 2004, Blöschl et al. 2007). Forests are likely to have more of an impact on seasonal flood regulation than on extreme events (Wilk et al. 2001), yet for many tropical watersheds, where data on runoff and total water yield is quite poor, flood regulation or mitigation by protected forests' remains an unpriced and undervalued life-support service (Pattanayak 2004).

Increasing interest in expanding the understanding of ecosystem benefits for reducing hazard risks and demonstrating these benefits to encourage the sustainable use and conservation of natural ecosystems is evident from the numerous recent publications and pilot projects (Renaud et al. 2016). Land cover change has the potential to influence hazard risk experienced by farmers, but it is also influenced by the type and location of farms, semi-urban areas and plantations which further mediates flood risk (Wheater and Evans 2009). This adds impetus to evaluating benefits derived from forests under protection and how these influence the vulnerability element of flood risk especially for rural, and often marginalized populations (Few 2003). This review points to the need to take an interdisciplinary methodological approach to overcome the challenges associated with incomplete or limited data, and view the relationship between forests, agricultural risk reduction and hazards through a broader methodological and conceptual lens.

Chapter 3: Conceptual background and research methodology

3.1 Introduction

This chapter presents the overarching conceptual framework and research design used to examine the role of forests in agricultural risk reduction in Madagascar. The theoretical guidance for this work comes from political ecology, the ecosystem services framework and sustainability of complex socio-ecological systems. Before introducing the research methodology, this chapter first discusses the relevance of an interdisciplinary approach to investigating the overarching research problem, the positionality of the researcher and the conceptual frameworks that underpin this study. The final two sections provide an overview of the methodological approaches adopted.

3.2 Conceptual frameworks

3.2.1 Political Ecology

Political ecology has its roots in the critiques of ecological anthropology and cultural ecology (Brown 1998). Blaikie and Brookfield (1987)'s influential work defines political ecology as a combination of political economy and ecology (p. 17), with the local, the state and the global as key components of this approach. It is concerned with the interactions between the state, non-state actors, and the physical environment (Forsyth 2004), thus providing a fitting lens through which to study the relationship between forests, the beneficiaries of forest ecosystem services and factors influencing forest management. Additionally, political ecology can be seen to have three areas of inquiry: historical analysis to understand contemporary situations, local site specific environmental change processes, and the linkages between local and wider geographical or societal forces (Neumann 1992). This thesis firstly adopts the political ecology approach by investigating the local use of forest resources and perceptions of their hazard mitigation benefits, and assessing consequent support for local forest management institutions that are part of a national network of forest associations. Secondly, the political ecology approach is reflected in this thesis through a multi-decadal analysis of trends in and interactions between biophysical, economic, social and governance variables for the wider socio-ecological system in Madagascar at the national scale.

3.2.2 Ecosystem services framework

The Millennium Ecosystem Assessment (MA) proposed four main classes of ecosystem services: i) provisioning services such as food, water, medicines, forest products, ii) regulating services such as climate regulation, water and air quality and flood control, iii) supporting services such as photosynthesis and nutrient cycling, and iv) cultural services such as spiritual beliefs, tourism and aesthetic values (MA 2005). While these are not meant to cover all contexts and applications, nevertheless this classification system has been one of the most widely used, contributing to the evolution of several more recent classification systems to support the assessment of ecosystem service benefits (Fisher et al. 2009). An important point to consider is that an ecosystem service exists because there are people who benefit from them (Fisher et al. 2009). That is, ecosystem services are benefits people derive from nature (Daily et al. 1997). Without exposed or potentially vulnerable populations, flood regulation or erosion control by forests cannot be considered as a final service. Likewise risk from flooding or other hazards emerges when there are specific populations exposed to the hazard (Wisner et al. 2004).

This thesis draws upon two particular lines of thought emerging from the ecosystem services framework. The first is that of trade-offs between different ecosystem service types – for example between clearing forests (which provide both regulating and provisioning services) and using the land to grow crops for food production (which can be considered a form of provisioning service (DeFries et al. 2004, Zhang et al. 2007). These trends are evident in many rapidly developing countries (Zhang et al. 2015). By all accounts this is also the case in Madagascar (Waeber et al. 2016). The question then is what does degrading ecosystems mean for the sustainability of agricultural systems like the ones found in Madagascar – characterized by low input and high labour?

The second line of inquiry associated with the consideration of ecosystem services also refers to an apparent trade-off. This is the apparent trade-off demonstrated by evidence of significant ecosystem degradation globally and for all ecosystem types in parallel with significant improvements in human wellbeing globally (MA 2005). This phenomenon is seen as the environmentalist's paradox (Raudsepp-Hearne et al. 2010) and forms one of the key hypothesis examined in Chapter 4.

3.2.3 Complex socio-ecological systems and co-evolutionary dynamics

The advantage of viewing the research aim of this study through the lens of a complex socio-ecological system is that of recognizing and accounting for the multiple ways in which people are a part of the natural environment and in turn shape its ecological outcomes (Anderies et al. 2004, Cote and Nightingale 2012). In trying to assess the role of forests in agricultural risks for smallholder farmers it is apparent that the direction of influence is bi-direction at the very least. Farmers affected by extreme weather hazards make certain decisions about forest uses and forest management which then feedbacks into hazard impacts via moderating regulating services. By allowing an investigation of the feedbacks and interactions between different system variables, changes in connectivity and time lags in responses between different variables can become apparent (Berkes and Folke 1992, Costanza et al. 2007, Ostrom 2009). In turn such knowledge can help identify critical thresholds beyond which a socio-ecological system can undergo a fundamental shift in its stable state, helping anticipate critical transitions (Scheffer et al. 2012). Such an approach is relevant in systems as simple as a lake undergoing eutrophication after nutrient pollution or a highly connected financial system vulnerable to any stressor leading to its collapse (Billio et al. 2010, Dearing et al. 2012). Thus, the frameworks of political ecology, ecosystem services and socio-ecological systems are intuitively linked and form a complementary base for the research performed for this study.

3.3 Rationale for an interdisciplinary research approach

This thesis focuses on the interactions between three distinct areas of research that are integrated within the same overarching research problem: forests and their role in the hydrological cycle, forest ecosystem services, and extreme weather hazards and agricultural risks experienced by smallholder farmers. The complex mixture of biophysical, socio-economic and geographic variables and factors influencing the relationship between land cover change and hazard risk to agricultural communities requires an approach to research that can bring together disparate disciplinary theories and methods to produce a level of understanding that is greater than the sum of its parts. This is in essence the central tenet of interdisciplinary research. Interdisciplinary approaches allow for the consolidation of knowledge from different spheres in order to solve complex environmental problems of global relevance (Acutt et al. 2000). Integrating methodologies from different disciplines permits a researcher to draw upon the concepts, theories and principles of reasoning of the various disciplines brought together under an interdisciplinary framework (Acutt et al. 2000, Moses and Knutsen 2010). Over the last fifteen years or more, scholars and funding bodies have recognized the need for interdisciplinary research to resolve urgent environmental problems that cut across the social and ecological spheres and thus require academics to transcend the boundaries of traditional disciplinary "ways of knowing" (Redclift 1998, Daily and Ehrlich 1999, Acutt et al. 2000). One of the challenges of such an approach is to ensure that the research takes a truly interdisciplinary focus, both in methods and theoretical guidance, rather than just being a combination of different disciplinary methods brought together. In order to ensure that interdisciplinarity is truly achieved, not only the process of research but also the outcomes should contribute to understanding and enhancing knowledge about both biophysical drivers and the social actors of a complex, interconnected problem area.

3.4 Positionality

This study is conducted from a pragmatist's viewpoint allowing for a focus on the research problem and questions, rather than being committed to any one system of knowledge or worldview. According to Creswell (2013), pragmatism permits a researcher to hold multiple worldviews and in doing so supports the choice of mixed methods for data collection and analysis. The focus of the pragmatic perspective is on the real world and applying the most relevant approaches to solving the problem at hand. In addition, pragmatism allows for the recognition of the social, political, historical and environmental context within which research is taking place (ibid.). The pragmatic perspective further supports the adoption of an interdisciplinary framework as it allows the researcher to draw upon different disciplines for theoretical and conceptual knowledge, real life understanding of the context of the problem and integration of this understanding into a unifying framework for the analysis of data (Creswell et al. 2011).

3.5 Study Design

There are two distinct sets of data used in answering the research questions identified in Chapter 1. The first research question relies upon the analysis of multi-decadal data on key system variables that can help characterize the socio-ecological system's behaviour and identify relationships and patterns in co-evolving parameters that define the system. The second set of data is based on fieldwork conducted over two seasons in Madagascar. The overall study design used for this thesis is a multi-phase design, with the first field season in July – September 2014 followed by a period of secondary data collection and preparation of the social research methods. This phase was followed by six months of fieldwork in northwest Madagascar (April – October 2015). A case study enables the researcher to investigate complexity and the particular attributes of the villages selected within the regions with opposing forest cover trajectories. Combining methods from the qualitative and quantitative sphere allow for validation, comparison and cross checking of the results (Creswell 2013). Table 1 lists the three research questions, the specific purpose each fills, the type of data needed and the methods for data collection and analysis.

Table 3.1 - Research questions, data needed and methods of data collection

Research Questions	Purpose	Data Needed	Data Collection/Analysis Methods
1. How can the conditions of and reciprocal interactions between key socio-ecological systems variables be characterised during the recent history of Madagascar?	Characterize the conditions, trade-offs and state of the socio-ecological system to identify key drivers and states at the national and district scale	Multi-decadal data on key system variables, including: forest cover, staple crop production, socioeconomic indicators of growth, human wellbeing and governance	Secondary sources of data including World Bank, FAO, NASA FIRMS, CHIRPS and Madagascar national statistics office (INSTAT) and disaster risk and management bureaus/ Times series analyses, sequential (dynamic) principal component analysis
2. Do extreme weather hazard experiences and consequent crop damages suffered by smallholder farmers in dry forest landscapes influence the perception of hazard mitigation benefits of forests?	Assess agricultural risks from extreme weather events for smallholder farmers; identify contributing socioeconomic and geographic factors, and identify which hazard impacts (if any) predict a positive perception of forests in hazard mitigation.	Experiences of climate variability and extreme events; hazard impacts suffered; crop damages estimated; Perception of forests' hazard mitigation services;	Household semi-structured questionnaire surveys and focus group discussions, including participatory mapping of hazard exposed areas within commune/ Descriptive statistics to characterize farming system and population in study site; Spatially mapping to represent areas of crop damages and perception of hazard mitigation services; Logistic regression to identify predictor variables.
3. How do deriving forest use benefits and perceiving hazard mitigation services from forests motivate participation of smallholder farmers in community forest management groups?	Identify the ecosystem services, including hazard mitigation services, derived from tropical seasonally dry forests by smallholder farmers; identify factors, including ES benefits that lead to support for forest management as a local collective land use decision.	List of various provisioning, cultural and regulating forest ecosystem services used or perceived as important for livelihoods; membership status in local community forest management group (VOI)	Household interviews using structured questionnaire and key informant interviews /Logistic regression to identify predictor variables.

The next section provides an overview of the methodological approaches used in this thesis to expand understanding of the socio-ecological system at the national and

Mahajanga II district scale followed by the description of the case study site and social research methods.

3.5.1 Methodological approaches for understanding trade-offs and system behaviour

This section focuses on the main methodological approaches used to inform the analysis of the socio-ecological system at the national and district scale in Madagascar. According to the theory of complex socio-ecological systems such as those represented by a state (Mahajanga II) or nation (Madagascar) social, ecological, biophysical and economic variables are expected to interact, with time lags and feedbacks that can cause trade-offs for example, between provisioning ecosystem services and regulating services, or reinforce the conditions observed in one set of variables or sectors (such as, crop production) over another (Liu et al. 2007). This complexity of relationships and patterns is observed only when the whole system is studied in an integrated manner, and not necessarily observed when social, ecological or biophysical processes are considered separately. This integration of the physical environment with the human, social and political factors, and drivers of change, is also a central tenet of political ecology (Blaikie and Brookfield 1987) }. By doing so in the context of Madagascar, this study contributes to the empirical gap between theories of complex socio-ecological systems and application to real world contexts at the regional, country or subnational scale with consequent applications for sustainable management, as noted by Zhang et al. (2015).

In order to expand the understanding of Madagascar as a country highly dependent upon its natural resource base, research presented in Chapter 4 takes two overarching methodological approaches. The first is to identify evidence of long-term degradation in regulating and provisioning ecosystem services, trends in human wellbeing and socioeconomic and governance attributes and biophysical stressors such as cyclones. The second line of inquiry is to identify changes in linkages or connectivity between different system components that can suggest changes in system phase. To establish these lines of evidence this study uses time series analysis of multiple variables, and sequential principal component analysis to assess changes in interactions between key components that can signal changes in system connectivity. These methods are further expanded in Chapter 4.

3.5.2 Methodological approaches case study data collection

3.5.2.1 Case study region and sample selection

Research questions 2 and 3 reflect the location specific context of environmental resource use as one of the key areas of study in political ecology ((Brown 1998). To investigate Research Questions 2 and 3, it was important to identify a study region that has experienced hazards linked to heavy rainfall events of different magnitudes over the last fifteen years; has natural resources'- dependent smallholder farmers who by the nature of their primary occupation are exposed to rainfall variability; and have people who are active forest users. Site selection occurred after the first fieldwork season in 2014. During this pilot fieldwork, focus group discussions, transect walks and key informant interviews were held in Mariarano *fokontany* to help make this selection. A *fokontany* is the smallest administrative unit with elected officials in Madagascar. These discussions helped establish a timeline of major heavy rainfall events experienced locally and provided a background understanding of the types of hazard impacts triggered by storm events from the perspective of local farmers. Examples of hazard impacts highlighted during this phase included fields damaged by siltation and the formation of small erosional gullies. 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. The residents of the two case study *fokontany,* Mariarano and Antanambao, actively utilize natural resources from the surrounding landscape and forests. The two *fokontany* with locations for villages surveyed during the study are shown in Fig 3.1.

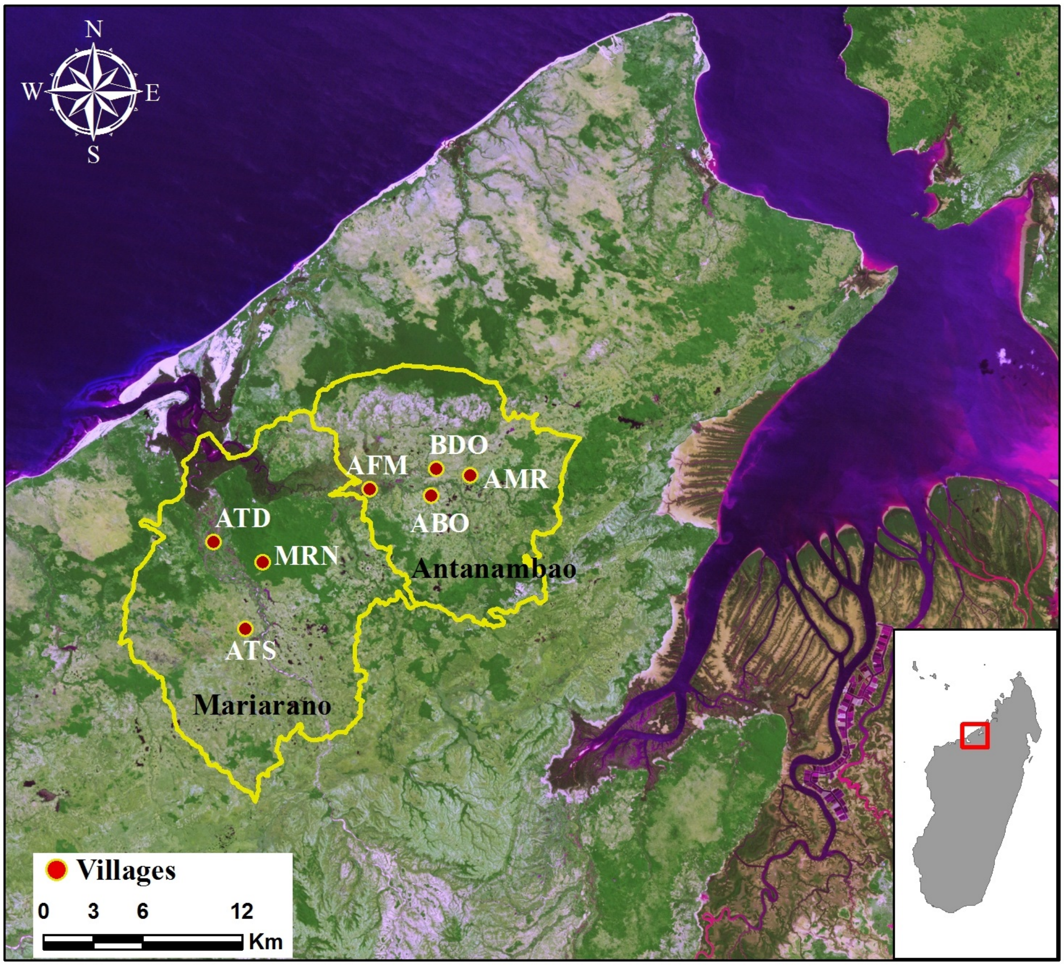

Fig. 3.1. Map showing the location of the study area within northwest Madagascar. The red dots indicate the 7 villages at which households were surveyed, the bold boundaries encompass the *fokontany* of Antanambao and Mariarano, within the commune of Mariarano.

Source: Landsat-TM 5, Year: 2009

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. The forests present within Mariarano *fokontany* are restricted to a comparatively higher elevation, on the Ankatsabe massif, with the rice fields and villages present in close proximity on the lowlands in the floodplains of the river. This location of the forests and the location of the villages that are part of the *fokontany* of Mariarano allows for a clearer demarcation of forest user groups who are predominantly from the same *fokontany* (pers. observation and through focus group discussions and key informant interviews conducted prior to household surveys). In contrast, the situation in Antanambao *fokontany* is such that forests are further away from the village locations and are used by residents from other *fokontany* within the commune, thus making the task of managing resource use and forest protection more challenging. 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 (PGM-E and GOM 2013).

Simple random sampling was used to select the household sample from a sampling frame that comprised adults between the ages of 26 – 70 years. As the study involved recalling hazard events and impacts on farms over a period of five years or longer, it was necessary to ensure that the respondents had been farming independently for at least that length of time. Structured interviews at the household level is common method used in social research studies (Bryman 2012, Mashi et al. 2015). For example, Brouwer et al. (2007) use a stratified sampling strategy to select villages and then select a random sample of households in each of these villages to assess risk from flooding and coping capacity for 700 households in Bangladesh.

Key informant interviews and focus group discussions are standard methods included within the participatory rural appraisal (PRA) toolbox and can be employed to identify general themes and collective experiences at the community level (Pelling 2007). PRA is a set of methods for data collection that has the potential to integrate the views of multiple participants together and that is often employed by researchers and practitioners including those from development organizations and relief agencies (ibid.). A focus group method is a form of group interview focused on specific themes where the researcher is interested in the material gathered from the interactions within the group (Bryman 2012). Pelling (2007) review the use of participatory research methods such as the PRA in disaster risk assessment. Focus group discussions are a qualitative research method that allow for a carefully selected group of people to meet and discuss specific questions posed by the researcher (Tapsell et al. 2002). Mercer et al. (2008) use participatory research techniques to assess the vulnerability of indigenous groups in Papua New Guinea to environmental hazards and develop a community disaster risk management plan. Another form of participatory research technique used in the field of disaster risk reduction is community participation in spatial mapping of local knowledge about flood hazard, manageability and coping strategies as identified by Peters-Guarin et al. (2012).

Although academic research is in essence extractive, participatory methods such as focus group interviews can allow community members to contribute ideas, express their opinions in their own terms and encourage discussion between group members to rediscover knowledge shared within the community (Mercer et al. 2008). Mercer et al (2008) list the limitations, advantages and ethical issues associated with participatory techniques for research (page 177).

3.5.2.2 Methods of data collection

The case study data collection comprised of three main types of data collection methods. Household surveys in seven villages with a total of 240 households, using a semi-structured questionnaire form the primary data collection method at the core of the analyses performed in Chapters 5 and 6. This questionnaire was first pilot tested in May 2015 and any confusing statements clarified and questions finalized. Each household interview was timed to take an hour of the respondent's time. Interviews were conducted in Malagasy by trained enumerators who were Malagasy graduates in forestry and agricultural sciences, and then translated into English during data entry. The researcher is conversant in basic Malagasy and learned key phrases that were regularly used to allow for accurate interpretation of the data. Regular data entry checks were performed to ensure accuracy in data gathered.

All focus group discussions and key informant interviews were audio recorded and later transcribed and translated by the enumerator and the researcher together. Both the pilot field season in September 2014 and the full field season in May – October 2015 occurred during the dry season, thus there is a season bias that may be linked also to respondent recall of information on events occurring during the rainy season or across several years. In this case, time markers that were commonly used to help people remember times during the year or specific years (for example, Cyclone Kamisy was a major, destructive storm to hit in 1984, and was commonly brought up especially by elders). Independence day, which falls in June, and New Year are major celebrations that were helpful during discussions of harvest, food intake and lean season.

Key informant interviews were conducted in parallel with the pilot testing of the household interviews. These interviews provided a more general context for land use and forest cover change, commonly experienced agricultural risks during the wet season and common uses of the forests and perceptions of their importance. The focus group discussions, which included an exercise in mapping areas of importance for different forest benefits and areas at risk from weather linked hazards, were conducted towards the end of the fieldwork after the majority of the household surveys were completed. This allowed for a more open sharing of information as the participants had become used to the presence of the research team in the area over the preceding months. Group discussions are prone to the “tyranny of participation” as described by Cooke and Kothari (2001), in which the more powerful voice their opinion or override others. In order to avoid such power dynamics we aimed to have participants with similar age ranges and separate groups for officers of the community forest groups. Where possible (if the number of participants in a focus group were sufficiently large) the participants were divided along gender lines to help ensure that the women participants would feel free to speak openly. This thesis did not specifically have a gender dimension, and most of the household survey respondents were men as the goal was to interview the household head.

The next three chapters 4 – 6 present the technical details of the methods and sources of data collected as well as the types of analyses performed to respond to each of the three overarching research questions.

Chapter 4: Madagascar: examining the naturalists' paradise through socio-ecological systems lens

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R. Dave conceived of, collated the data, conducted the analysis and wrote the paper. Co-authors provided input into data analysis and comments on manuscript draft.

4.1 Introduction

Madagascar's late 20th century struggles with poverty alleviation and biodiversity conservation, specifically the conservation of its iconic forests and wildlife, has captured the world's imagination for several decades now (Myers et al. 2000, Kull 2014). The pattern and extent of deforestation witnessed on the island has been attributed primarily to the growing rural population, farming communities and their traditional practice of slash and burn agriculture (*tavy*) (Kull 2002, Gorenflo et al. 2011, Scales 2012), prescribing a Malthusian view of the drivers of this crisis (McConnell 2002). However, at least for two decades now, researchers have known that large tracts of forests were lost during periods of low populations during the first forty years of colonial rule. While conservationists often see forest clearing for agriculture, especially the tradition of *tavy*, slash and burn rice production, as the proximate drivers of forest loss (Green and Sussman 1990, Norris 2006), others trace the roots of forest loss, erosion, transition from food self-sufficiency to a net food importer to the colonial era land use, forest exploitation, cash crops and trade policies of the French colonial government (Jarosz 1993, Horning 2008). Researchers have viewed and tried to explain the seemingly intractable problems of stemming forest loss and improving livelihoods faced by Madagascar through multiple, and at times disparate disciplinary lenses. Duffy (2006a) examines Madagascar's experience over the last thirty years of interacting with and adopting policies directed by the transnational network of international environmental organizations (NGOs), bilateral and multilateral aid agencies, private companies and international financial institutions and finds that overall it fits the mould of a governance state wherein external bodies have an inordinate influence on national policy setting. Much of this external influence on policy arises from the inordinate level of dependence upon foreign financial assistance for most government functions (Waeber et al. 2016) of which funds to support environmental goals form a non-negligible portion (Kull 2014).

Once called the naturalist's paradise, Madagascar has long been considered one of most important hotspots of Earth's biodiversity because of both the high levels of endemism of its native plant and animal species and the threats to their survival (Myers et al. 2000). The country's status as a global hotspot for biodiversity has resulted in over thirty years of sustained foreign donor aid to support conservation efforts (Horning 2008, Waeber et al. 2016), with a multitude of those projects focused on integrating rural development with conservation initiatives (Kull 2014). This biological wealth is juxtaposed against a predominantly agrarian society where 65 % of the adult workforce is involved in farming. Rice production is the foremost agricultural activity (Minten et al. 2006). While Madagascar emerged as a net rice exporting country after independence in 1960, within ten years the country was dependent upon imports for this basic food item (Barrett 1994). Malnourishment due to insufficient food intake is widespread, and strong variability in prices and availability of staple food crops across the calendar year drives seasonal reduction in calories consumed during the wet months which pushes more people into poverty (Dostie et al. 2002). Madagascar performs dismally on most human development indicators, ranking 154 out of 188 countries on the Human Development Index[2]. A recent study finds that the country failed to make progress towards most of the indicators of the Millennium Development Goals (Waeber et al. 2015).

Factors such as repeated exposure to strong tropical storms and cyclones (Fitchett and Grab 2014) are thought to influence performance of the country's agricultural sector (GOM and GFDRR 2008), and argued to have long lasting welfare impacts through increasing the sensitivity and vulnerability of its population to external shocks and exacerbating poverty (Barrett et al. 2011, Francken et al. 2012). Such self-reinforcing processes that impact health and well-being point to a poverty trap situation. A poverty

[2] UN HDR: Human Development Index. http://hdr.undp.org/en/content/human-development-index-hdi
Accessed September 10, 2016

trap is defined as any self-reinforcing mechanism that causes poverty to persist (Barrett et al. 2011:13098). In addition to such exogenous factors, frequent multiple periods of political unrest appear to impact both conservation and development goals (Zinner et al. 2014). Studies have shown that exposure to multiple stressors, which often include political, economic and social shocks in addition to climatic ones has detrimental consequences especially in low incoming developing countries like Madagascar (O'Brien et al. 2004).

Decades of research focusing on poor rice yields and low levels of input seen in the agricultural sector (Minten et al. 2006, Minten and Barrett 2008), understanding and identifying the patterns of agricultural expansion, slash and burn cultivation and forest areas lost or degraded (Horning Rabesahala 2004, Brinkmann et al. 2014, Zaehringer et al. 2016) and on the continuing conservation challenges has yielded a broad range of insights from different disciplinary perspectives on the problems facing agriculture, livelihoods, poverty alleviation and conservation (Horning 2008, Rasolofoson et al. 2016). There is however a need to see socio-ecological interactions through a systems lens using an integrated approach to identify possible exchanges, associations or dissociations between different social, ecological, economic and governance conditions evident in Madagascar over multi-decadal timeframes and at multiple scales. Such an approach helps to detect key systems behaviour, fast and slow changing variables, pressures and drivers that interact and create feedbacks at different time intervals thereby contributing to these apparent development failures and setbacks.

Taking an integrated systems approach allows for interdependencies inherent in a complex, multi-scalar socio-ecological system (SES) to be evaluated, key parameters and processes understood and phases of the system state to be identified. Globally, it is evident that meeting food and immediate human needs has transformed large swathes of forests into farmland or urban centres and undermined the ecosystem services that support the very same production systems (Foley et al. 2005, MA 2005). Some of the questions that an integrated systems approach enables researchers to investigate include: i) What are the trade-offs apparent between appropriating land for crop production and the deteriorating condition of natural ecosystems such as forests and the services derived from these forests in Madagascar?, ii) Does a diminishing natural resource base lead to declines in rice yields and production because of the loss of ecosystem regulating services and consequent feedbacks, and what are the other, economic, biophysical and governance factors that interact with these ecosystem services' parameters to influence these outcomes?, iii) How do frequent extreme weather events, in terms of cyclones and intense tropical storms affect the rice production systems that to date has supported the wellbeing of the majority of the country? Another advantage of the systems' approach is the ability to discern different phases of the system and the implications of these states for the management objectives. When key system parameters change, it can lead to a shift in the system dynamics, reaching a critical threshold and experiencing a regime shift (Folke 2006, Barrett et al. 2011). The theory of different basins of attraction as states of existence with thresholds that tip systems (households, resource systems such as fisheries, economic systems) into alternate states is applicable to social and economic systems as well as ecological (Holling 2001). Barrett and Constas (2014) advocate a resilience approach to poverty alleviation efforts, proposing the development resilience framework as a way to help address chronic poverty through the adoption of an integrated systems' approach that recognizes the interconnectedness and interdependence between ecosystems and livelihoods. The authors argue that risk events can push households from one alternate stable state of human wellbeing to another (for instance from the "non-poor" to one of chronic poverty) and that stressors are often mediated by the local social and cultural norms and institutions.

In this chapter, a systems' approach is used to analyse the situation in Madagascar in order to address three overarching objectives, relying upon available social, economic, ecological and governance variables and biophysical stressors:

1) Identify historical trajectories exhibited by, and detect trade-offs in, key system components represented by: a) ecosystem services including crop production and forest area, b) human wellbeing outcomes such as mortality rate for children under five and the number of malnourished people, and c) system attributes such as economic indicators of wealth, biophysical hazards and performance on governance indicators.
2) Distinguish interactions between these components over time, which may indicate convergence or divergence in the trajectories of key system properties (e.g.

agricultural production) and other variables, such as indicators of the impacts of cyclones.

3) Examine the implications of these trade-offs and interactions on the overall system state at the district and national scale and assess whether these conditions point to a poverty trap situation.

The analyses presented here apply a co-evolutionary approach through which to address these objectives and examine the complex interactions between key variables during the recent history of Madagascar as represented by multi-decadal data at the national scale. In a complex socio-ecological system, a co-evolutionary approach allows for the examination of how different social, biophysical and institutional elements of the system interact and influence each other over a historical time period, shedding light on how interconnected the system maybe (de Araujo Barbosa et al. 2016). Additionally it is argued that a multi-decadal, evolutionary perspective plays more than just a contextual role - it can help to identify "slow and fast" and changing patterns of divergence and convergence between variables representing a system (Dearing et al. 2012). This approach has been applied to examine socio-ecological systems elsewhere in the world, such as in China and Bangladesh (Zhang et al. 2015, Hossain et al. 2016). However, there is a dearth of such approaches in the analysis of recent trends and trajectories of change in the socio-ecological systems of Sub-Saharan Africa, including Madagascar.

4.2 Materials and Methods

4.2.1 Madagascar as a complex socio-ecological system

Madagascar is a "rice economy par excellence" (Minten et al. 2006) and one frequently hears that "rice is politics" (Kull 2014). After gaining independence from France in 1960 Madagascar opted to stay within *La Zone Franc*, maintaining economic policies such as poll and cattle tax, and keeping the Malagasy Franc pegged to the French currency (Barrett 1994) which had long term repercussions on the economic development of the country and led to the ousting of the government of the first president of independent Madagascar (the "First Republic") and a transition to a socialist regime. Subsequently, the efforts of international donors and non–governmental groups (NGOs) to promote conservation and forest management efforts in Madagascar since the 1980s have led to its characterization as a transnational governance state (Duffy 2006b). To date the economy has been supported to a large extent through its i) agricultural output, which for most of its history has been based on clearing forested land for cultivation, whether subsistence or cash, has low input and high labour, and which is exposed to weather extremes such as cyclones and droughts especially for predominantly rain fed farming system found in Madagascar and to global market and price fluctuations (Barrett 1994, Moser et al. 2009) ii) nature based tourism, spurred by the endemic forest species found nowhere else, and subject to booms and bust driven by global and national events (Rakotondramaro and Andriamasy 2016) and iii) overseas development assistance (ODA) which is a combination of grants and loans, with conditions attached and is highly variable (Kull 2014, Waeber et al. 2016).

Understanding how these different sectors interact and influence each other nationally is an important first step to comprehend the complexity of the Malagasy sustainable development conundrum. Secondly, to assess key system drivers and improving the understanding of trade-offs in variables that impact human development and ecological sustainability it is necessary to identify which of these system variables exhibit similar evolutionary trajectories and interactions at the subnational and local scales. This goal is addressed at the national and sub-national scales in this chapter, by using national and district level statistics on social, economic and ecological conditions and biophysical stressors in Madagascar (Fig A4 2).

The district of Mahajanga II was chosen as the sub-national unit of analysis for three main reasons: i) it is a rural district in northwest Madagascar, dominated by smallholder, mainly subsistence farms that are cut off from urban centres for the duration of the rainy season (3-4 months) each year, yet is a primary source of crops, fruits and vegetables for the city of Mahajanga, the fourth largest city in the country and the second port city, ii) its dry deciduous forest fragments hold high biodiversity but lack sustainable management across the board, thus some forests are being managed locally to produce charcoal for sale in the city while other forest fragments are being managed for sustainable use and biodiversity conservation (PGM-E and GOM 2013), and iii) the region is highly exposed to cyclones, having experienced at least eight in the last twelve years (Data compiled from CRED and Madagascar CPGU).

In the following section, the theoretical foundations of the application of co-evolution to socio-ecological systems is first discussed. The different types of component variables used in this chapter, the data sources and limitations, and methods of analysis are then presented and discussed. This is followed by empirical analysis focusing on the three research objectives identified in Section 4.1.

4.2.2 Conceptual approaches

Two conceptual frameworks provide the foundation to meet the objectives identified for this study. The first is that of ecosystem services. While there are several frameworks elaborating the ecosystem services approach (Daily and Matson 2008, Mace et al. 2012) and the concept itself has now accumulated over twenty years of research (Daily et al. 1997), we draw upon the highly influential Millennium Ecosystem Assessment (MA) (MA 2005) to define the production systems and the benefits derived by people from nature that are considered here. The Millennium Assessment categorizes nature's benefits into four sets of services: provisioning, regulating, supporting and cultural. While these are not meant to cover all contexts and applications, nevertheless this classification system has been one of the most widely used, contributing to the evolution of several more recent classification systems to support the assessment of ecosystem service benefits (Fisher et al. 2009). Although there are critiques of this approach, for instance due to the susceptibility to double count a set of services as both regulating and supporting (ibid.), this framework is well suited for a consideration of trade-offs between these categories and with indicators of human wellbeing (MA 2005, Rodríguez et al. 2006, Bennett et al. 2009). Ecosystem services approach explicitly necessitates the involvement of beneficiaries – the demand for and distribution and magnitude of ecosystem services are important features to consider in addition to underlying ecosystem processes (Chan et al. 2006). Using the MA, agricultural food output, fisheries and livestock production are characterised as "provisioning services" – the tangible goods derived from farming, fishing and using land to support cattle; and forest area as a proxy for regulating ecosystem services, for example flood and erosion regulation, while acknowledging that forests are also sources of provisioning services such as timber, fuel wood, raw materials and food.

The second conceptual and methodological approach is that of co-evolutionary approaches to understand historical evolution in order to anticipate current and future conditions for complex socio-ecological systems (Dearing et al. 2012). The application of this perspective to socio-ecological systems, extending back to the 1980s (Norgaard 1987), allows for human-environment interactions to be seen as part of co-evolving system within which each is continually feeding into the other, modifying and adapting in response to changes (Berkes and Folke 1992). Co-evolutionary approaches applied to real world complex socio-ecological systems at the regional or even national scale also provide insights derived from an integrated systems approach relevant to poverty alleviation and policy setting (Barrett et al. 2011, Zhang et al. 2015).

This chapter uses a co-evolutionary approach with time series analyses to identify trends in key variables and use sequential principal component analysis to examine the system connectivity in order to interpret system behaviour (Zheng et al. 2012). Using this approach allows for the evaluation of interactions between various social, economic and biophysical variables in a coupled human-environmental system and identify patterns and relationships that characterize these (Rammel et al. 2007).

4.2.3 Data collection and compilation

4.2.3.1 National Scale

The variables compiled here fall into three overarching categories: i) provisioning ecosystem services indicated by crop production, livestock and fisheries, and forest area, ii) system attributes that are commonly used indicators of economic growth, expenditure on health and education, governance performance and repeated biophysical stressors such as cyclones, and iii) human wellbeing outcomes in terms of education attainment, malnourishment and wealth indicators (Table 4.1). The availability of long term data in Madagascar, especially for bio-physical variables is challenging, as in many other data poor regions of the developing world, precluding the inclusion of regulatory ecosystem services such as soil erosion indicators or water quality. For this analysis all available data on economic, social and biophysical system variables at the national scale and where possible for the district of Mahajanga II were collected from the World Bank, the Food and Agricultural Organization and national Madagascar statistical organisation (INSTAT) and the national disaster risk management agencies (BNGRC and CPGU) (Table 4.1). While economic growth indicators do not always reflect greater welfare for individuals in society (Bulte et al. 2005), and country statistics reported to FAO are known to under-report capture fisheries (as an example), this chapter is constrained by the nature of this study and data availability to use these indicators.

At the national scale, "provisioning ecosystem services" are considered ecosystem benefits such as food production, represented by crop production specifically, the staple crops of rice, cassava and maize, and vanilla, an important cash crop, and by fisheries including capture fisheries and aquaculture. Shrimp aquaculture, vanilla and sugar form part of Madagascar's primary export industries. Cattle, an important livestock animal both economically and culturally, is also included as an indicator of provisioning services. Forest cover represents available timber, raw materials, energy sources and non-timber forest products. More than 90 % of Madagascar's residents depend upon traditional solid biomass fuel for cooking such as fuel wood or charcoal (IEA 2014). Charcoal production around the capital city is mainly from plantations of pine and eucalyptus, established during the colonial era, however in the west and other regions of the country, natural forests are predominantly used to produce charcoal. Illegal logging for Madagascar's precious rosewood and ebony trees from protected areas is driven by the huge overseas demand, exploiting the poverty of villagers living close to protected areas. Deforestation and its drivers are well documented across the country (Mayaux et al. 2000, Harper et al. 2007). No reliable records exist of how much timber is legally harvested and exported. The importance and relevance of forests as sources of provisioning ecosystem services notwithstanding, in this paper we use forest area as a proxy regulating ecosystem services, for instance of reducing floods and mitigating erosion and sedimentation.

The term "system attributes" is used to denote factors that represent the broader socio-ecological system in i) economic terms, for example, GDP at market prices, export value of goods and services, contribution to the GDP by the industrial, agricultural and tourism sectors, and the amount of Overseas Development Assistance (ODA) received per capita; ii) governance terms by an aggregate governance rank comparing Madagascar to the rest of the world, measuring performance on rule of law, political stability, control of corruption, voice and accountability, government effectiveness, the proportion of public investment in health and education, iii) demographic and land use terms by rural population and agricultural land area, and iv) in terms of biophysical hazards by the number of people affected by cyclones and tropical storms. Tourism brings revenue through visa fees, hotel tax, national park fees, and contributes about 15 % to the GDP, is mainly driven by nature tourism, thus is linked to conservation.

A third set of variables, referred to in this chapter as "human wellbeing (HWB) outcomes" is used to capture societal wellbeing and includes measures such as: i) the mortality rate for under five year olds, the number of people who remain malnourished, the per capita GNI (at 2011 purchasing power parity), the proportion of pupils who reach the final grade of primary school, the proportion of people living under USD 1.90 per day as an indicator of poverty levels. These are commonly used indicators to measure human development across the world[3]. While recognizing that governance indicators such as corruption and public investments in health and education can be considered human wellbeing outcomes by some measures, in this analysis they are better suited as key system attributes with implications for outcomes felt at the individual level. Additionally, only five data points (5 years) of the GINI coefficient data are available, with the most recent World Bank estimated score assigned it a value of 40.6.

4.2.3.2 District Scale

To identify the type of interactions and connectivity evident at the district scale for Mahajanga II, district level data was compiled on provisioning services of crop productions and forest cover, biophysical characteristics of the number of fires per year and average yearly precipitation. Crop production data are derived from a combination of FAO data for years 1997, 2003 and 2014 and from INSTAT for years 2000-2013. Tropical cyclones and storms that make landfall over eastern, north and western Madagascar have an impact on the weather and rainfall amounts in this northwest district. Thus, rainfall levels for the district are used as a means of capturing the influence of extreme weather events on the system. Precipitation data for 1981 – 2015 were derived from the Climate Hazards' group Infrared Precipitation with Stations (CHIRPS) dataset, a high resolution, long term record that has been validated for use in multiple countries including Ethiopia and Cyprus (Funk et al. 2015, Katsanos et al. 2016).

[3] World Development Indicators http://data.worldbank.org/data-catalog/world-development-indicators
Accessed July 2016

In the dry climate of Mahajanga II, fires are an important system component, used to clear new pastures after the rains, and at times to clear land for maize crops. Satellite data on fires was collated for 1997 – 2015 from two different sources. The European Space Agency's AATSR was used for fires detected 1997 to November 2000, and for years 2001 – 2016 from active fires data detected by the University of Maryland and NASA's *Fire Information for Resource Management Systems (FIRMS)* project's archive download tool[4] (Giglio et al. 2003, Xianlin et al. 2006). The ESA/AATSR fire detection yields significantly limited events compared to those from NASA FIRMS for consecutive years, which is a common issue found in other studies.

Forest cover data at the national scale is available from the World Bank's data portal (sourced from FAO), however, data for forest cover change in the district of Mahajanga II was produced for the years 1993-2016 from satellite data derived from LANDSAT. The image scene had less than 10 % cloud cover, and the segment used for the district had no cloud cover. The images were corrected for atmospheric effects and the digital numbers were converted to top of atmosphere reflectance (TOA). The corrected images were classified into forested areas and non-forested using a decision tree classification algorithm (Grinand et al. 2013, Hansen et al. 2016).

[4] Accessed at https://firms.modaps.eosdis.nasa.gov/download/

Table 4.1 - Variables used as system components, scale, time period of availability and sources.

Variable Category	Indicator	Scale	Time Period	Source
Provisioning Ecosystem Service: Food Production	Rice produced	National/ District	National: 1966 -2014 District: 1990 – 2014	INSTAT; FAOSTAT
	Cassava produced	National/ District	National: 1966 -2014 District: 1990 – 2015	INSTAT; FAOSTAT
	Maize produced	National/ District	National: 1966 -2014 District: 1990 - 2016	INSTAT; FAOSTAT
	Cattle numbers	National	1961-2013	FAOSTAT
	Capture Fisheries	National	1966 -2015	World Bank
	Aquaculture	National	1976 -2015	World Bank
Provisioning ES: Timber, non-timber forest products, raw materials	Forest area	National/ District	National: 1990 – 2014 District: 1993 - 2015	World Bank and LANDSAT
Human wellbeing outcomes	Under 5 child mortality	National	1961-2015	World Bank
	Persistence to last grade of primary, total (% of cohort)	National	1961-2015	World Bank
	GNI per capita (2011 PPP)	National	1990 - 2015	World Bank
	Proportion of people malnourished	National	1996 - 2015	World Bank
	Proportion living under the poverty line at $ 1.90 / day	National	1990 -2015	World Bank
	% of GDP invested in health	National	1995 - 2015	World Bank
	% of GDP invested in education	National	1974-2015	World Bank
Economic, demographic, biophysical and governance indicators as system attributes	Overseas development assistance, ODA (% of GDP, current USD value and per capita)	National	1961-2015	World Bank
	GDP, current USD value	National	1966- 2015	
	% of GDP invested in health	National	1995 - 2015	World Bank
	Industry value added (% of GDP)	National	1966 -2015	World Bank
	Agriculture value added (% of GDP)	National	1966 -2015	World Bank
	Tourism revenue (% of GDP)	National	1988 - 2015	The World Travel and Tourism Council database
	Agricultural Land Area	National	1966-2014	World Bank
	Rural population	National	1990 -2015	INSTAT
	Aggregate governance indicator	National	1996 -2015	World Bank
	Number of tropical storms and cyclones	National	1981 - 2015	BNGRC, EM-DATA
	Total number of people affected by cyclones	National	1981 -2015	BNGRC, EM-DATA
	Fires detected	District	1997 - 2015	ESA/AASTR and NASA FIRMS
	Precipitation (yearly average)	District	1981-2015	CHIRPS

4.2.4 Data analysis

All the variables used here are standardized z – scores in order to allow for relevant comparisons between the different social, economic and biophysical components' states and trajectories of change over a multi-decadal timeframe. A z-score is the measure of how many standard deviations below or above the population mean a raw score is[5]**.** Time series of data was analysed to identify trajectories of change and evolution of systems' variables within the three overarching categories at the national and district scales (Table 1). Simple linear relationships between indicators of ecosystem services, system attributes and wellbeing outcomes were examined using correlation analyses bivariate scatter plots (Hossain et al. 2016).

Sequential principal component analysis (PCA), used in detecting risks to the financial system, especially in the aftermath of the 2008 financial crisis, can help identify the systemic risk over specific windows of time (Billio et al. 2010). If the key system component variables are highly correlated then the higher order principle components will explain a greater amount of the variability than any of the original variables (Abson et al. 2012). A moving-window sequential PCA used to identify the correlations between variables over time is thus used to identify how connected or not different system variables may be and thus the inherent risk or stability of the system in response to stressors (Zhang et al. 2015). Assessing the connectivity between different components of a socio-ecological system is a step towards understanding how the system may react to perturbations either through gradual change or through experiencing a critical transition in its state (Scheffer et al. 2012). A system with more homogenous components that are connected to each other in a complex network may have a higher resistance to change up to a certain point but be more susceptible to critical transitions once threshold stressors on interacting variables is reached (Scheffer et al. 2012). This analytical lens has been applied to diverse systems from financial, health, ecological and complex socio-ecological systems to identify and possibly pre-empt risk events (Resnicow and Page 2008).

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[5] $z = \frac{(x - \mu)}{\sigma}$, where z refers to z-score, x is the value of a given variable, μ is the mean of the total set of observations for a given variable, and σ is the standard deviation

In this study, the sequential PCA method is applied to time series data on i) combined provisioning services and human wellbeing outcomes, ii) combined socioeconomic and biophysical attributes of the system and human wellbeing (HWB) outcomes, and iii) combined provisioning services and HWB outcomes for connectivity analysis at the national scale, and for a subset of system attributes and provisioning services at the district scale for Mahajanga II. A ten-year moving window is used for analysis at the national scale (1981 – 2015), and a five-year window is used at the district scale (1990 – 2015). In this analysis, the first principal component explains greater than 50 % of the observed variance for all the datasets, thus PCA 1 values are presented for the connectivity analysis.

Finally, associations are tested between agricultural production and forest cover on the one hand as indicators of provisioning services, and a subset of system attributes including indicators of economic growth, governance performance, impacts of weather hazards associated with cyclones, and wealth per capita at the national and district scale, using linear regression analyses to identify significant relationships.

4.3 Results

4.3.1 Trajectories and system evolution

4.3.1.1 Changes in food provisioning services

Rice production is the primary staple and the main subsistence crop in Madagascar, practiced by over 85 % of farmers growing this staple on usually small 0.15 – 0.20 ha plots (Minten et al. 2006). Madagascar, which in 1972 was a net exporter of rice, was by 1977 a net importer of this staple food, and in 1978 had to spend almost as much as its total foreign exchange to import 200,000 tonnes of rice (Mukonoweshuro 1990). The Malagasy government introduced market liberalization for paddy rice in 1985 removing price controls and state monopolies in domestic and international trade as part of the suite of structural adjustment programs instituted in exchange for international loans to meet expenditures (Berg 1989, Barrett 1994). However, both production and yield for the most important staple crop, rice, has suffered, leading to the reintroduction of government policies to distribute rice nationally and control the market (Minten et al. 2006). The tradition of allowing hillside or rain-fed rice fields to recover through shifting agriculture, meant that in the 1970s, the fallow period was 15 – 20 years in some cases, allowing the land to regenerate and replenish nutrients naturally (Styger et al. 2007). While rice production increased steadily over the ~ 50-year period of 1966– 2015 (Fig. 4.1), reaching a peak of 4.5 million tonnes average during 2009-2012, it is insufficient to feed the growing population. Rice production declined by six per cent in 2013 – 2015 due to late and insufficient rains and the effects of storms (FAO Rice Market Monitor 2015[6]). Production and yield increases are not keeping pace with increased daily calorific intake from rice – 50.7 % of per capita calorie intake per day is from rice – with per capita rice consumption usually topping world tables (Minten and Barrett 2008). Among the other staple crops, cassava and maize show a similar increase in production levels, though with steep reductions seen between the years 2002 and 2005. Rice yield in Madagascar went from 1.82 tonnes/ha in 1961, at the time of independence, to 1.95 tonnes/ha in 1970 at the height of the post-colonial period of high investments in agricultural production and rural infrastructure projects under the First Republic (Barrett 1994). Between 1976 and 1982, yields declined from 1.92 tonnes/ha to the low of 1.66 tonnes / ha. Over the last two decades the fallow periods have shortened with many farmers farming their fields throughout the year, without adding fertilizers, thus leading to a loss of soil fertility and consequently a reduction or at best stagnation of crop yield (Styger et al. 2007).

Cattle and fish imports from Madagascar were banned due to disease outbreak by the E.U. in 1997, which translated into significant decreases in cattle numbers (Fig 4.1), reaching a low in 2005. Cattle numbers have rebounded since then and are increasing. Capture fisheries, which rose steadily from the mid 1980s have declined sharply from 2007 onwards (Fig 4.1). On the other hand, aquaculture, of which shrimp aquaculture is an important export commodity, shows an upward trajectory overall.

4.3.1.2 Evolution of forested land

Madagascar was the first country in Africa to develop a strategic plan for environmental management, the National Environmental Action Plan, implemented in three five year phases, starting in 1991 (Raik 2007). Fig. 4.1 shows a steady decline in the area under

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[6] Rice Market Monitor, December 2015. Accessed: Aug 15, 2016 http://www.fao.org/fileadmin/templates/est/COMM_MARKETS_MONITORING/Rice/Images/RMM/RMM_DEC15_H.pdf

forest cover since 1990, when regular forest cover monitoring began using remotely sensed satellite images of land cover (Harper et al. 2007). Prior to 1990, aerial photographs estimated forest cover at 159,000 square km in 1953, of which up to 40 % were lost by 2000 (ibid). While estimates vary between different sources due to differences in methodology (FAO 2000, WB, and (Mayaux et al. 2000), all point to a steady decline in the area of forests in Madagascar as seen in Fig. 4.1.

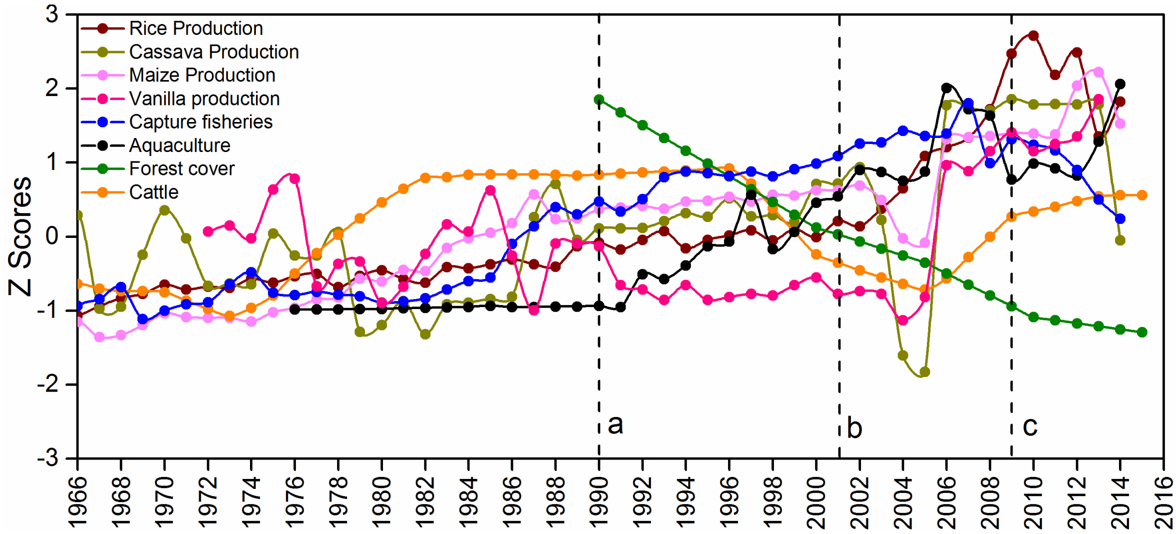

Figure 4.1 - Provisioning services: annual staple crops' production, vanilla, livestock production (cattle), capture fisheries and aquaculture, and forest cover. a) 1990 was the start of the first of three five-year National Environmental Action Plans (NEAP)(Raik 2007); b) 2001 political instability during a period of uncertainty following a disputed presidential election; this was followed by 2003-2004 cyclone season with damaging cyclones Gafilo and Elita impacting the country in early 2004 c) 2009 witnessed a political *coup d'état* and a subsequent withdrawal of foreign donor aid for all but basic humanitarian aid, the removal of Madagascar from the African Growth and Opportunity Act, a region trade agreement with the US (AGOA), which led to the loss of thousands of jobs in the manufacturing sector, a proliferation in illegal rosewood harvest to markets in Asia, and further disruptions in the country's law and order, increasing corruption, decreased investment in public welfare programs and slowed progress towards the achievement of the Millennium Development Goals (Kull 2014, Waeber et al. 2016).

4.3.1.3 Economic, social, governance and biophysical system attributes

The biophysical, macro-economic and governance indictors considered here as system attributes show mixed trajectories of decline and improvements (Fig 4.2a). Agricultural value added to the economy is an important indicator of the economic gains from this reliance on commodities. The value added to the national economy (value added to GDP) by the agricultural sector combines the output from crop and livestock production, forestry, fisheries and hunting, and has changed little since mid 1960s, going from 25 % in 1966 to just over 26.40 % in 2014, however, over the thirty-year period between 1986 – 2015, agricultural value added to the GDP declined by approx. 3.5 standard deviations. It was at its peak from the mid 1970s to the mid 80s, reflecting Madagascar's status as a primarily agrarian society at the time. At the same time, industrial value added, which includes mining, water, gas, electricity, and manufacturing has seen an increase overall to 16.03 %, after a sharp decline to 9.9 % in 1995. Tourism is one of the most important sectors for Madagascar and its second largest foreign exchange earner (Rakotondramaro and Andriamasy 2016), contributing 14 % to GDP in 2014. Tourism is however acutely responsive to political upheavals, which is reflected in a 30 % drop in tourist numbers between 2008 and 2009 when the latest crisis hit. ODA forms an important component of the state's budget and stood at 583 million USD in 2014. Between 2000 and 2008 the ODA comprised 77.8 - 76.1 % of the total government expenses. In 2011, ODA comprised 46.3 % of the total government expenditure (WB 2015 Country Statistics).

Madagascar's GDP in 2015 was 9.9 million USD, amounting to 0.02 % of the world economy. Madagascar's GDP shows a fluctuating pattern: in 2008, the economy grew at 7.8 %, in 2009, however after the 2009 political crisis the economy shrank by 11 percentage points (GDP growth rate at - 4.04 %). Over the period of 1966 to 2015, economic crises occurred at 2001-2002 in the aftermath of the second to last political uncertainty with election results in 2000, and between 1979 and 1981 (both showing an 18 percentage points shrinkage to negative economic growth). These growth patterns are reflected in the minimal and declining public expenditure on health and education services (Fig 4.2b).

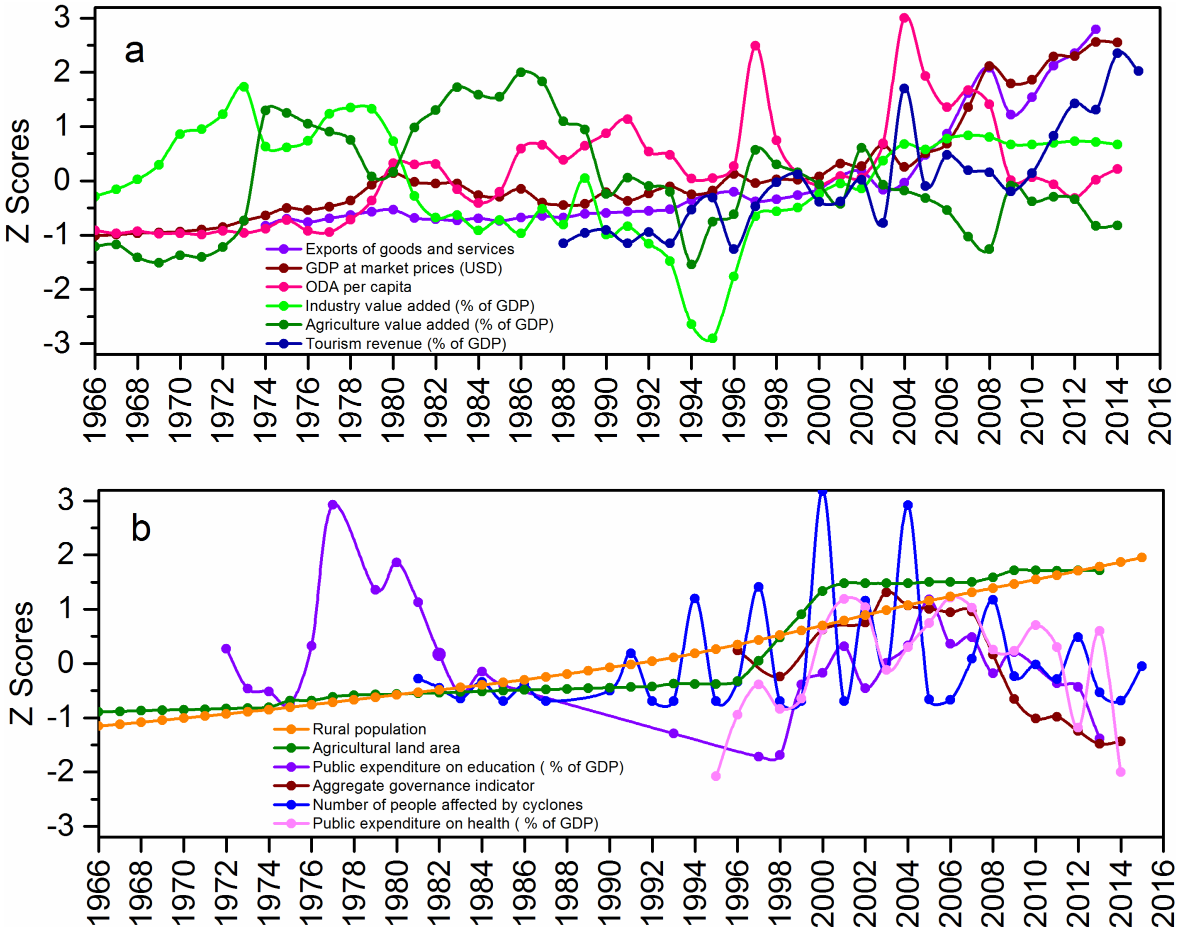

Figure 4.2 - Multi-decadal trends in key system attributes: 4.2a) Trends in economic indicators including ODA per capita, GDP, the contribution of tourism, industry and agriculture to GDP and export of goods and service; 4.2b). Trends in rural population, agricultural land area, government expenditures on health and education, number of people affected by cyclones, and the aggregate governance indicator.

Madagascar is currently ranked 158th based upon the proportion of GDP dedicated to health facilities (less than 1.6 %). Investment in education has suffered throughout as seen in Fig. 2b, with two peaks – in 1977 when 5 % of the GDP was devoted to education spending and in 2005 when 3.8 % was devoted to this sector. However, the trend since 2005, over the last 10 years is one of steady decline in public investment in education. Data on the aggregate indicator of governance ranking (Fig. 4.2b) show a decline of approximately 2.5 std. deviations from the peak in 2003 to 2016. Agricultural land area showed a gradual increase for forty years during 1966-1996 and then a rapid increase of approximately 2 std. deviations in four years from 1996 to 2000, while rural population shows a steady increase of almost 3 std. deviations. The rural population has increased at a steady pace with the proportion of arable land available to each family declining by 34 % to 0.19 ha between 1990 and 2010 (Alvarez et al. 2014). Staple food production per capita has declined accompanied by degradation of land and soil resources (Alvarez et al. 2014).

Cyclones are a repeated hydro-meteorological hazard faced by Madagascar, with most years experiencing two to three cyclones in one season over the period of 1981 – 2015 (Table 4.2). The impact of this chronic exposure is experienced in the form of loss of life, injuries, damage to agricultural production, destruction of homes and infrastructure. Cyclones in Madagascar have a serious impact on sustained development efforts undermining gains made. Cyclone Kamisy in 1984 caused damages worth 250 million USD. More recently in 2004 Cyclone Gafilo also caused over 250 million in damages and affected 700,000 people with an estimate 257 people killed (Table 4.2). Soon after Gafilo, Cyclone Elita made landfall over Madagascar three times and affected five of six provinces of Madagascar. The death toll from these two cyclones combined in 2004 was 395 people, with over a million people affected and severe damage to infrastructure, including roads, schools and hospitals (Table 4.2). Subsequently, there have been 1 – 3 cyclone landfalls on average each year since 2004, causing repeated damage to the already poor road infrastructure, causing losses in agricultural production and leaving hundreds of thousands without shelter or injured, and over the long term impacting the social and economic wellbeing outcomes of the population (Fig 4.2b).

Table 4.2 Cyclone landfalls across Madagascar with known damages, number of deaths and number of affected people; empty spaces denote no data; Source EM - DAT and CPGU, Madagascar.

Year	Cyclone numbers	USD Damages (000's $)	Total number of people affected	Total Deaths
1981	1	250000	118000	107
1982	1	250000	70000	92
1983	1	25000	13560	42
1984	2	250000	100215	68
1985	0	0	0	0
1986	1	150000	84309	99
1987	0	0	0	0
1988	1			
1989	1			
1990	1		55346	46
1991	1		250000	36
1992	0	0	0	0
1993	0	0	0	0
1994	4	10200	540051	212
1995	0	0	0	0
1996	1		100000	9
1997	2	50000	600000	174
1998	0	0	0	0
1999	0	0	0	0
2000	2	9000	1106209	153
2001	0	0	0	0
2002	3	181	528100	23
2003	3		162750	89
2004	2	250000	1032429	395
2005	1		7985	78
2006	2		6516	4
2007	3	240000	222511	84
2008	3	60000	533166	105
2009	3	5000	130799	27
2010	1		192132	120
2011	1		115215	35
2012	3	100000	335599	112
2013	2	25000	44879	51
2014	1		1736	17
2015	2	46000	182437	95

4.3.1.4 Human wellbeing outcomes

In terms of its performance on the common human development goals of improving access to education and healthcare, reducing hunger and poverty, Madagascar's record is dismal (Fig 4.3). Notwithstanding gains in reducing mortality of children under the age of 5, the number of malnourished people in the country is increasing. While the rural population and land devoted to agriculture have both increased, food imports have also increased. In addition, the proportion of students completing primary school, as an indicator of education gains is declining despite a few years of steady improvements (e.g. between 1996 and 2000, and from 2001–2004).

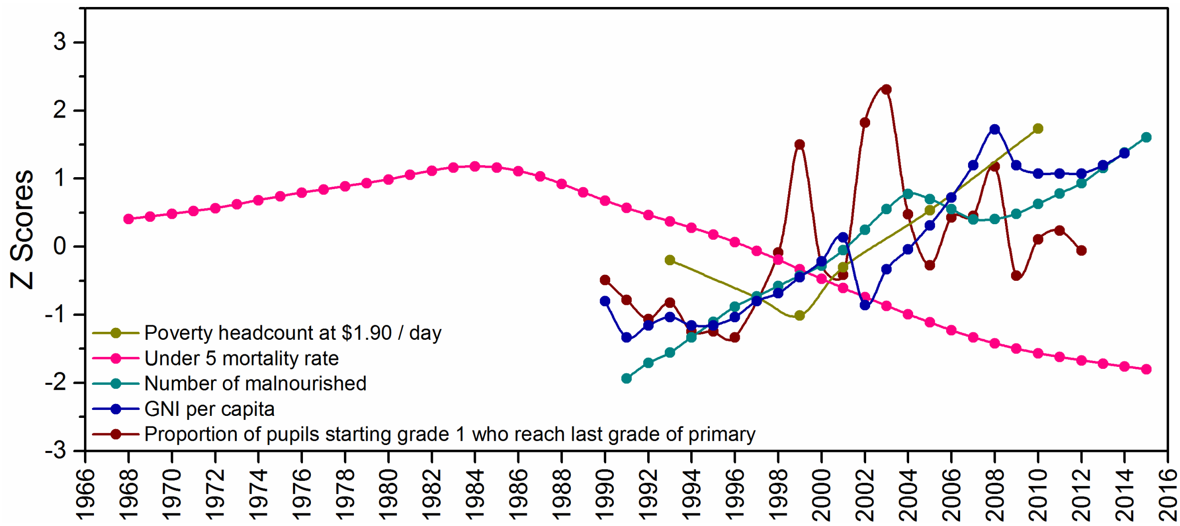

Figure 4.3 - Human wellbeing trends indicate a reduction in child mortality rates over the fifty-year period, yet the number of people living below $1.90 is increasing, as is the number of malnourished people, primary school completion rates are declining. GNI per capita at 2011 purchasing power parity has increased though with some reductions between 2000 and 2002 and from 2008 to 2009 (the two most recent periods of political turmoil).

Another trend that speaks volumes is the increasing proportion of people living under $1.90 a day, which is on an upward trajectory. The annual GNI per capita at 2011 purchasing power parity is $1400, an increase of only $400 over the period of 1990 – 2015, with Madagascar ranked 206[7] out of 216 countries.

[7] http://data.worldbank.org/data-catalog/GNI-per-capita-Atlas-and-PPP-table

4.3.1.5 Trajectories of biophysical system attributes and provisioning services at district scale

In the case of Mahajanga II, precipitation patterns show strong inter-annual variability in rainfall amounts received during the wet season lasting from late November to April. While rice production shows one or two peaks in 1992 and 2012, there are several periods of lower production, notably in 2013, when the national production levels were also considerably reduced due to lower rains (Fig 4.4). Maize production increased from the late 1990s to 2008, stabilizing somewhat thereafter. Cassava, another staple crop important especially in the wet season when household stocks of rice are low, declined starting 1999 after an initial increase, with production stabilizing after 2006. The number of fires detected increase from 2000 steadily to 2005, start to decrease, reaching a low in 2013, but then increasing again in 2014. Forest cover in this district is in decline even though areas under protection have seen regeneration.

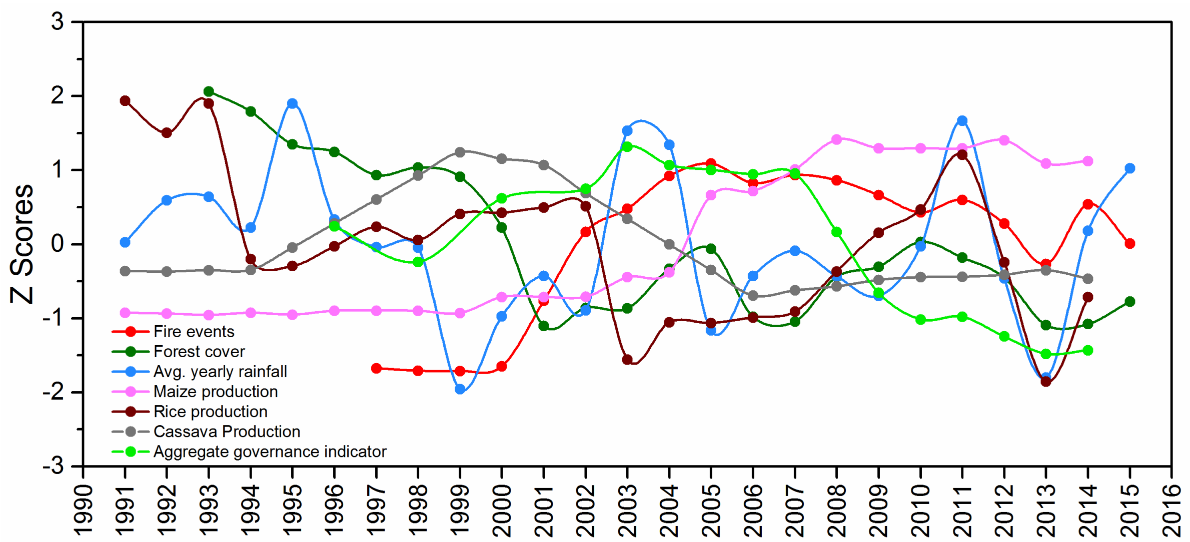

Figure 4.4 - Trends in the number of fire events, average precipitation, forest cover and staple crops produced (rice, cassava and maize) for the district of Mahajanga II, and national governance performance ranking over the same period.

4.3.2 System connectedness

Sequential PCA analysis of variables at the national level and for the district of Mahajanga II are presented in Fig 4.5. At the national level, Fig 4.5 presents the curves for PC 1: i) for provisioning services and human wellbeing outcomes (Fig. 4.5a), ii) for outcomes and system attributes (Fig 4.5b), and iii) for provisioning services and system attributes (Fig 4.5c). At the national level, the figures suggest an overall trend of declining connectivity, though with intermittent increases in connectivity, between the economic, governance and biophysical system attributes considered here and the outcomes of societal wellbeing (Fig 4.5b), and similar decreasing connectivity between provisioning services and outcomes of wellbeing (Fig 4.5a) over the period analysed. However, despite this slow decline, it is worthwhile to note that PC 1 values still explain 50 % or greater variance in these variables with the exception of one window where the explained variance falls below 50 % (indicating less connectivity) for HWB outcomes and provisioning services (Fig. 4.5a). On the other hand, the decline in connectivity between wellbeing outcomes and system drivers is noticeable over the time period considered (ranging from over 80 % variance to 50 % variance explained). Fig. 4.5d shows the connectivity between variables for provisioning services and system attributes at the district scale for Mahajanga II.

Connectivity within the system at the district level between provisioning services and the two system attributes of precipitation and governance performance (Fig. 4.5d) and at the national level between provisioning services and system attributes (Fig 4.5 c) do not show a trend in any one direction – exhibiting consistent periods of higher connectivity (50 % or greater variance explained by PC 1) and period of lower connectivity. Nevertheless, for all four sets of PCA analyses, it must be noted that similar analyses over a much longer timeframe (greater than ~35 years available for this study) may yield different trends.

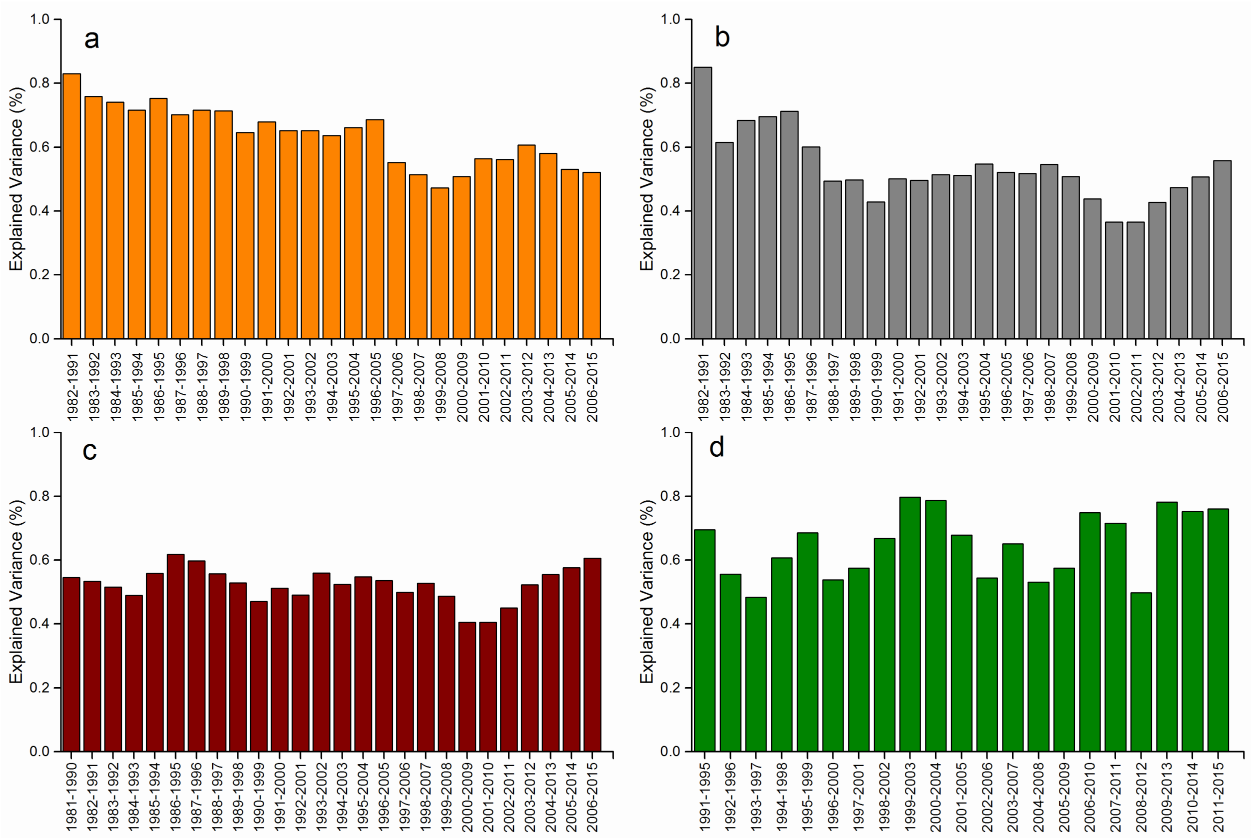

Figure 4.5 - Sequential PCA with a 10-year window, variance explained by PC1, results for a) Provisioning services and human well-being outcomes, b) system attributes and well-being outcomes, c) Provisioning services and system attributes, and with a 5-year window for d) combined provisioning services and subset of system attributes (governance ranking and number of fires) for the district of Mahajanga II.

4.3.3 Association between economic and social attributes of the system and human wellbeing

Bivariate plots (Fig 4.6) show a clear negative association between forest cover and the GNI per capita (PPP at 2011 values) and aggregate staple crop production, and positive associations between increases in aggregate staple crop production (rice, cassava and maize) and increases in GNI per capita, though with a new downward trend suggesting changes in the positive associations. Forest areas declined less steeply with increases in agricultural land area for the first half of the 1990s, but declines increased sharply since 2001. Forested areas and GNI per capita show a negative association, as is to be expected, with the predominant role of agriculture in the economy. No clear associations were seen between agricultural production and cyclone damages in monetary terms, or the number of people affected by cyclones.

Correlation analyses performed on variables at the national scale showed a positive association between forest cover and governance rank, suggesting that years with higher governance were also years when the forest cover was higher. Expressed in another way, over the recent years, times series data show forest cover has continued to decline and accompanied by a decline in governance ranking.

Rice production showed a significant negative association with forest cover and food imports, and a positive association with GDP per capita. Maize production coincided with periods when the governance rank was low, while increased cassava production coincided with periods of low food imports and ODA per capita. All three crops are negatively associated with forest cover as seen also from the bivariate plots.

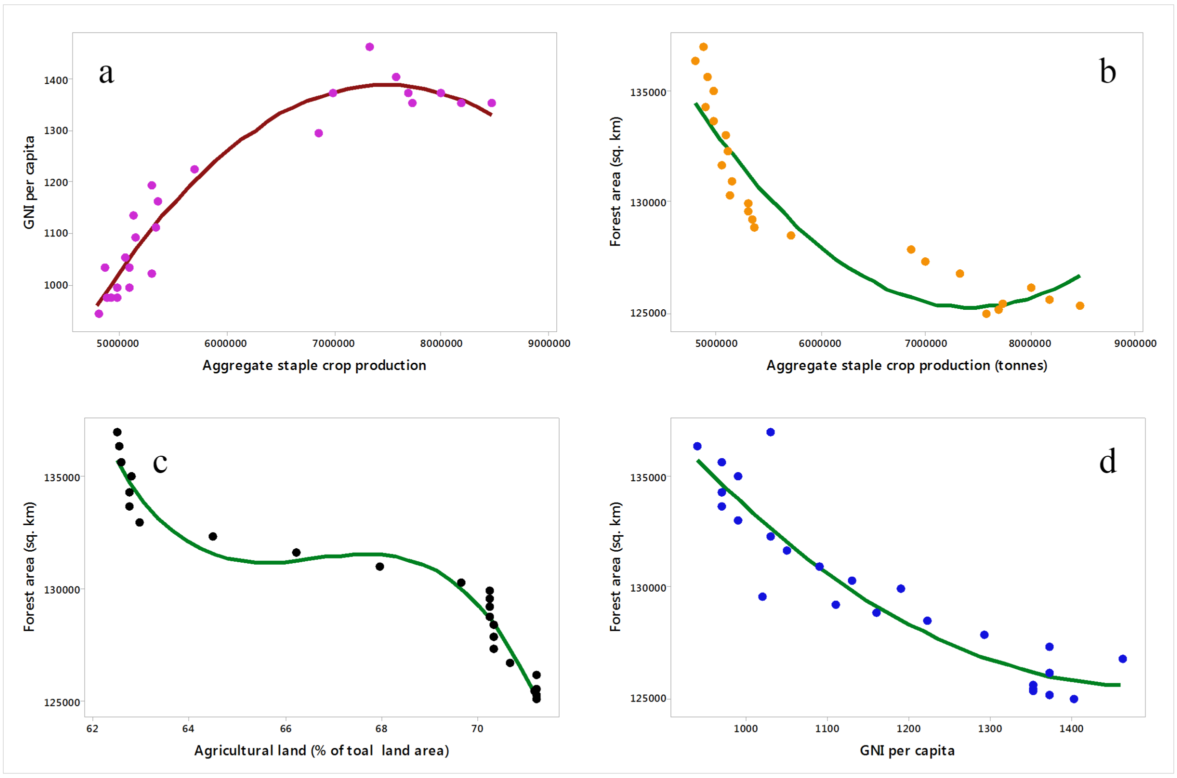

Figure 4.6 - Bivariate plots exhibiting relationships between economic indicators, forested area and aggregate crop production: a) Economic wellbeing shows a slowing down of growth with increase in staple crop production forest area, b) higher levels of aggregate staple crop production is associated with lower levels of forest cover, c) forest area shows slow decline over a period of a few years but rapid decline with agricultural land area reaching 70 %, and d) inverse relationship is seen between declining forest cover with increasing GNI per capita.

4.4 Discussion

4.4.1 Multi-decadal trends in provisioning services, system attributes and human wellbeing outcomes

The contrasting trends in the provisioning services of agricultural and livestock production against forest cover decline (Fig 4.1) indicate a trade-off between these ecosystem services, consistent with trends seen across the world (MA 2005). The social, governance and economic context for these trends is one of low and at times, negative GDP growth, declining performance on key governance performance indicators and a high level of dependence upon external aid, which in itself exhibits high variability and is vulnerable to international and national political events and global market forces. Additionally, damages from cyclones have risen steadily in terms of the number of people affected, with frequent years of multiple, intense tropical storms and cyclones affecting the country's infrastructure, crop outputs, and lives, such as the intense cyclone season of 2004. Improved records and more attention to disaster risks in recent years allows for more consistent information over the last decade or so. However, there is a chronic, regular risk of cyclones in Madagascar as seen from studies of long term records (Fitchett and Grab 2014). Despite this chronic exposure to cyclones, we were unable to find a bivariate association between the staple crop output and the number of people affected or monetary damages during 1981 – 2015. This relationship is perhaps better studied with local level data through case studies in order to identify impacts to subsistence farm households (Rakotobe et al. 2016).

Madagascar's two recent political crises dominate its recent past. However, political transitions and contrasting government policies form part of the narrative of this country's history since independence from France in 1960 (Minten et al. 2006, Kull 2014). These policies follow trends in the popular world development paradigm of the day such as the adoption of nationalization policies between the mid '70s and '80s, followed by the abrupt adoption of a neo-liberal model imposed by international donors as conditions on loans (ibid.). Trends shown here may be traced back to the beginning of the 20th century during the first forty years of colonial rule in Madagascar, when formerly surplus rice producing areas in the country underwent a transformation to net importer status driven by a mix of emphasis on coffee production for export, low producer prices for rice, labour shortage and frequent cyclones causing rain-fed rice fields to be abandoned (Jarosz 1993). Lack of spatial integration of rice markets across the island, caused in part due to the poor infrastructure, contributes to the strong, negative association between commune specific rice prices and production levels with consequences for the poorest farmers who tend to be net buyers of rice (Minten and Barrett 2008). Lower rice prices during the harvest season and higher prices during the lean seasons, which also coincide with the rainy season, have been shown to lead to a greater level of insecurity in the more remote rural areas (Ibid).

Declining performance on education and malnutrition indicators signal that at a national scale common human wellbeing indicators are not being met at the same time as Madagascar's inhabitants are suffering from depleted natural resources, declining food production and frequent episodes of political crises. Education investment initially suffered as a consequence of the formal structural adjustment policies in the mid 1980s imposed upon developing countries in return for loans and grants from the World Bank and IMF which led to dismantling of government public investment programs (as it did across most developing countries). Thus, while the overall index of gross national income (GNI) per capita has increased, the proportion of people living in extreme poverty (below $ 1.90) has also increased. In essence Madagascar has experienced a degradation of its natural resource base without experiencing a concomitant improvement in the lives of its rural population (> 65% of the population) and with considerable urban poverty. Thus, we can conclude that unlike in other developing countries, in Madagascar the idea that natural capital conversion to other capitals underpins more sustainable livelihood strategies in not borne out. This finding is in contrast to the environmentalist's paradox – that of improving human wellbeing seen in many parts of the world despite deteriorating ecosystems and declining ecosystem services (Raudsepp-Hearne et al. 2010).

The loss of forest cover is seen as the primary cause of the biodiversity crisis (Harper et al. 2007); it is also linked to increased levels of soil erosion, degradation and a loss of watershed services such as erosion control and the regulation of dry season water flow and floods and consequent silting of rice fields (Kramer et al. 1997, Bakoariniaina et al. 2006, Minten et al. 2006). Most of the remaining forest cover is now under some form of protection and formal management (Norris 2006, Gardner et al. 2013, Waeber et al. 2016), including several areas managed by community groups (Rasolofoson et al. 2016), preventing smallholder farmers from clearing forested areas for farming (McConnell 2002). Consequently, improvements in livelihoods for farmers can only occur with increased rice and other staple crops' productivity, which in turn requires investment and prioritization of the agricultural sector. Since 2000 there has been a proliferation of community based forest management groups, established through the forest management decentralization process initiated under the NEAP in the late 1990s (Raik 2007, Rasolofoson et al. 2016). These groups have been established with the intent of pursuing both livelihood and biodiversity conservation objectives in general, though in reality the objectives for each community managed area differ across the island. Additionally, local communities and the NGOs who mediate the establishment of these management regimes often have dissimilar understandings of the objectives of the groups (Scales 2011). It is unclear to what extent livelihood improvements are actually supported by the existence of community forest management groups in Madagascar.

Trends over 1990 – 2015 for the district of Mahajanga II show higher variability, which could be due to the shorter timeframe over which the data are available. However, viewing these trends at a sub-national scale expands our understanding of the apparent trade-offs between provisioning and regulating services and the high levels of variability in the interactions between key system components of forest cover, staple food crop production (rice, maize and cassava), and the system properties of precipitation patterns (with peaks during years with multiple cyclones and tropical storms), fires and governance performance. Mahajanga II falls within the greater basin of the Betisboka River, which flows west from the central highlands and shows dramatic levels of laterite sediments erosion, with estimates for soil erosion along the river channel contributing 3600 $t \cdot km^{-2} \cdot a^{-1}$ (Raharimahefa and Kusky 2010). There has been widespread loss of the deciduous forests to agricultural and livestock production, planting of natural wetlands with rice crops and the production of charcoal for the city of Mahajanga in this rural district (Raharimahefa and Kusky 2010). Maize and cassava are used as secondary sources of food, especially important during periods of low harvest. Maize fields are often associated with fires used to clear forest areas in western Madagascar. Fire used to clear forest land for cultivation and grasslands for cattle pastures is also thought to have led to the large-scale transformation of various landscapes in Madagascar and the extinction of megafauna found in the fossil record, including in this region during the early settlement period by humans leading to what could be characterised as a shift from one stable state of forests to another dominated by grasslands (Burns et al. 2016). An additional aspect of the use of fire in Madagascar is as a tool of protest by local people (Kull 2002). Rice production fell drastically in 2003-2004 nationally with a concomitant increase in prices, this fall in production is seen for Mahajanga II as well, accompanied by an observed rise in maize produced during this period.

4.4.2 System connectedness

The results of the sequential PCA provides insight into the system's connectivity, and indicate an emerging decoupling between human wellbeing outcome indicators of malnutrition, education attainment and income when combined with i) the provisioning services (Fig 4.5a) and ii) the system attributes (Fig 4.5b). Connectivity between these social, economic and ecological variables could indicate that the system is more resistant to stress until a critical threshold is passed when the system undergoes abrupt changes as described by Scheffer et al. (2012). Agricultural production, which during the 1960s and 70s appeared to be an engine of economic growth, has not kept pace with food demand of a growing population (growth rate at 3 % per year). Taking the example of rice, yield and productivity growth rates are at 1.1 %, much lower than the population growth rate (Minten et al. 2006). The fact that current production and yield levels are insufficient to feed Madagascar's population makes the country dependent upon imported rice. On the one hand, food imports are not consistent and depend upon the capacity of national accounts to pay for them (Fig. A 4.1). On the other hand, most of the population remains too poor to be able to purchase sufficient rice and other food items, increasing its vulnerability to the vagaries of political turmoil and crop damages from weather extremes and insect pests, such as the locust invasions of recent years and persistent droughts in the south. Even though agricultural production has increased, forest loss has continued without clear long-term benefits for Malagasy society. Each year during the rainy season, more than a million more people fall into poverty due to a shortage in available cereal stocks, the high prices of rice, and inaccessibility for most rural regions due to poor road infrastructure, with most secondary roads becoming impassable in the rainy season (Dostie et al. 2002). This is both a symptom of insufficient rice production and as the outcome of the type of subsistence dominated farming in place due to poor investment in agriculture and agricultural markets. Consequently, Madagascar suffers from one of the lowest calorific intakes per capita with average per capita calorie consumption declining by about 16 % in the thirty years from 1970 – 2000 (Minten et al. 2006). The welfare trade-off for poorer Malagasy, for example, between engaging children in subsistence agriculture and education, are evident and reflect similar trends elsewhere (MA 2005).

The apparent decline in connectivity between human wellbeing outcomes and system attributes of GDP, ODA per capita, and the growing contribution of tourism, declining contribution of agriculture and highly varying contribution of industry to the GDP, can potentially be seen as an indication of a stagnating socioeconomic system, caught up in a poverty trap (Carter and Barrett 2006) especially as we have also shown that most human development outcome indicators are declining. These results reflect the many mechanisms through which poverty traps and environmental conditions are interlinked. These include those of political failures of poor governance and corruption, high levels of dependence upon a limited set of natural resources, common exposure and vulnerability both people and natural ecosystems to external shocks and the lack of informed management caused by ignoring non-linear dynamics and feedbacks between socioeconomic and ecological system components (Barrett et al. 2011). Additionally, it has been argued that dependence upon external aid fosters dependencies and corruption (Waeber et al. 2016), with some studies arguing that it can lead to a relationship of mutualism as diverse donors justify their, at times, competing priorities and approaches with the help of national government partners (Horning 2008). Several studies have examined the relationship between foreign donor aid and biodiversity conservation efforts over the last thirty years (Kull 2014, Waeber et al. 2016). Despite this concerted effort to address forest loss, deforestation has proceeded at different rates across the island exhibiting spatial variation in forest loss and shows a steady upward trend. This lack effectiveness of conservation efforts, particularly in the national parks system, has been attributed to a myriad of causes ranging from agricultural practices, fires set to clear fields or create pastures, or as a form of protest, with evident infraction of rules leading to fires and loss of forests in protected areas under state management across the country (e.g. Ankarafantsika) (Horning 2008). The variability in the sequential PCA on combined provisioning services and socio-economic and biophysical system attributes, and the high variability shown in the sequential PCA results for Mahajanga II can be construed as signs of an instability in the system (Zhang et al. 2015) characterised by high exposure to inter-annual rainfall variability, forest loss, and primarily rain fed agriculture, complicated by additional stressors in the form of political crises, lack of governance reform and frequent exposure to tropical storms and cyclones.

The research presented here has shown that forest cover decreased steeply up to a point with increasing agricultural land area and staple crop production, with some slow stabilization with increasing staple crop production seen at later stages (Fig 4.6). Within the tropics, the degradation of ecosystems and forest loss, with an expanding agricultural frontier is not unique to Madagascar (Zaehringer et al. 2016), however, it is evident that Madagascar is suffering from a degradation of its environmental resources, including forest cover and soil fertility and with not much progress made on any of the important indicators of wellbeing, economic growth or governance reform. These feedback loops between diminishing forests and other ecosystem services, low productivity and human wellbeing outcomes, together with the variability in GDP (which in itself is not a sufficient indicator of individual wellbeing), point to a series of incongruences in the international argument on how to achieve development outcomes while promoting environmental sustainability.

4.5 Conclusion

This chapter applies a co-evolutionary lens to analyse multi-decadal trends and interrelationships for Madagascar as a whole complex socio-ecological system at the national and district scales. This study demonstrates that system components may be in states of high variability or displaying declining strength of interactions, which indicates a decoupling of system components, such that, for example increasing staple crop output is no longer sufficient to meet majority of development needs or indeed that decreasing forest cover as a proxy for deteriorating environmental conditions does not necessarily indicate an enhance agricultural output. While lower connectivity might, in systems like the financial markets, indicate a degree of stability, in this case of Madagascar we argue that this system behaviour points instead to a stagnations and poverty trap situation. Additionally, it is shown that the trade-offs demonstrated between food production and forest area are not accompanied by an overall increase in human wellbeing, measured through indicators such as education and health.

This is an exploratory analysis that integrates provisioning ecosystem service indicators of crop production, with forest cover, conventional economic growth variables and commonly used wellbeing outcomes over multiple decades to identify large scale interactions and temporal changes in the system. We have shown the growing divergence between provisioning services, key system attributes and human wellbeing outcomes; indicating that unlike the process of improved human wellbeing seen in many places, in Madagascar neither technological innovation nor sufficient food production have managed to decouple wellbeing from ecosystem services. Furthermore, it is possible that declining regulating ecosystem services are now feeding back into crop production in the continued absence of an explicit rural development strategy.

These results indicate that a depreciation of environment resources in order to enhance food production does not always lead to sustained and widespread improvements in human wellbeing. For a country that is considered a hotspot for globally valued biodiversity, it is apparent that governance performance and improved agricultural production systems are necessary first steps to achieving sustainability of the natural and agricultural resource base of the economy. Rice production and GDP growth are even now positively linked, yet will need to occur without much further loss of natural forests if the commitments to conserving the country's rare biodiversity are to be honoured. The growing contribution of tourism, which is to a large part drawn by Madagascar's wildlife and forests, will need to spur greater economic growth for a larger section of society, however, its sustainability depends upon the conservation of the pockets of unique wildlife and habitat found in Madagascar.

This is the first attempt to analyse and explain interacting, cross-sectoral variables and system components using an evolutionary approach in Madagascar. The analyses presented here have identified important questions that have relevance to household vulnerability, differences in hazards experienced and consequent land use including forest management decisions. These are better answered through local scale investigations, including identifying the nature of welfare impacts from repeated exposure of the rain-fed subsistence crop production systems to weather hazards (e.g. due to cyclones), whether communities and local institutions are better able to consider the implications of forest loss on agricultural production and finally, do take action to improve land use and forest management.

Chapter 5: Do perceived hazard mitigation benefits of forests affect hazard experiences in dry forest landscapes? A case study in Madagascar

This chapter is under review as a scientific publication in the journal Applied Geography as:

Radhika Dave, Emma L. Tompkins, Kate Schreckenberg (2016). Do perceived hazard mitigation benefits of forests affect hazard experiences in dry forest landscapes? A case study in Madagascar.

Data from this chapter were also presented at the *Tyndall Centre PhD Conference*, University of East Anglia, Norwich, April 2016

The global flood model for Madagascar was provided by collaborators Dr. Chris Sampson and Dr. Andrew Smith of SSBN Ltd.

5.1 Introduction

The majority of the world's farmers are smallholder farmers. They practice mostly traditional forms of agricultural production, in diverse ecological, social and economic environments and contribute over 80 % of the share of food consumed in developing countries (Vignola et al. 2015). Smallholder farming in low income or transitional economies is usually defined as agricultural production predominantly with family labour, on plots of land not larger than two hectares, with low levels of purchased inputs, and usually with the primary purpose of meeting a family's own consumption needs and as the main source of household income (Morton 2007, Tittonell et al. 2010). In the arid and semi-arid regions of the tropics, such as countries of Sub Saharan Africa, smallholder farmers regularly live with high levels of intra-annual and inter-annual climate variability, low annual rainfall and a higher degree of susceptibility to weather shocks (Salinger et al. 2005). As such smallholder farmers are exposed to all types of shocks ranging from floods to droughts, crop pests and diseases (Morton 2007, Harvey et al. 2014).

Typically, coping with agricultural risks includes the use of natural resources from the surrounding landscape, such as non-timber forest products, and complex mixtures of a variety of plants and animals as part of a diverse livelihood base (Morton 2007). Several studies have demonstrated the use of natural forests or savannah woodlands by smallholder farmers, including harvesting of wood and thatch as building materials, edible fruits and wild plants, and hunting small animals for personal consumption and for sale (Paumgarten 2005, Delacote 2007, Völker and Waibel 2010). In addition, some studies distinguish between those who use forest resources as part of a wider livelihood strategy on a regular basis, and those who use forest resources as a means of coping with emergencies (Shackleton and Shackleton 2004). Over the last decade, this understanding of forests as safety nets has been extended to reveal the role of forests in supporting forest-edge households to adapt to climate variability and change (Fisher et al. 2010). While these authors find no evidence of anticipatory adaptation benefits arising from forests, they do acknowledge reactive/coping benefits especially for the resource poor, bringing the lens back to the benefits of forests as providers of safety nets (Takasaki et al. 2004). In contrast to these case studies, a global comparative study finds little evidence of the use of forest resources as safety nets against shocks or as consumption and gap fillers during times of seasonal resource constraints, concluding instead that the contribution of forests to regular income generation is under-recognised (Wunder et al. 2014b).

This leads to the question, why would the presence of forests increase the ability to cope? It is hypothesized that there is a complex relationship between climatic shocks, hazard experiences of forest edge dwellers and forest use, notably, that previous experiences of hazards influence people’s perception of the role of forests in moderating the impact of such hazards, which in turn leads to greater support for sustainable forest management. Hence, the very existence of climatic shocks and variability contributes to an awareness of the hazard mitigation function of forests and in turn to improved forest management, which improves forest quality, which in turn improves people’s ability to cope with shocks and stress. This complex but important hypothesis is tested in this chapter.

In addition to the forest-safety net literature, our hypothesis is informed by studies on catchment hydrology effects of forest cover change. It is generally thought that forest degradation, conversion or regeneration all influence water flow in the streams and rivers including peak run-off after storms, floods and dry season base flow and that these effects are more apparent at small scales (Bruijnzeel 2004). However, there is ongoing debate derived from a lack of conclusive evidence in the forest hydrology literature that can be generalized across scales and regions (Bruijnzeel 2004, Bradshaw et al. 2007, Van Dijk et al. 2009). The study presented in this chapter takes a different methodological approach to this debate, drawing upon the political ecology framework (Brown 1998) to examine smallholder farmers' perspectives on the possible relationships between forests and storm hazard mitigation, and whether such forest benefits of providing regulatory ecosystem services are indeed perceived to be important.

Climate variability including the frequency and intensity of extreme events is expected to increase in the future for some regions (IPCC 2012) and these changes are likely to impact agricultural yield more than changes in the mean climate (Rowhani et al. 2011). Climate change and associated extreme weather events and seasonal shifts will increase stressors faced by smallholder farmers (Tambo and Abdoulaye 2013, Vignola et al. 2015). Previous experience of hazards is an important factor influencing disaster risk preparedness (Tompkins et al. 2009). However, there is a dearth of studies examining the relationship between farmers' experience of hazards and their perceptions of the role of forests in regulating floods and other storm related hazards that can influence the willingness to support natural forest management, regeneration or restoration. The few studies found in the literature point to a mixed picture with regards to how farmers' recognition of forest services influences support for forest regeneration or management initiatives in Brazil and Ghana (Silvano et al. 2005, Danquah 2015).

This chapter examines how prior experiences of weather extremes and the nature of impacts influence local perceptions and knowledge, factors instrumental in influencing management of forest resources, mitigating landscape degradation and enabling appropriate interventions to support agricultural production in the face of climatic variability and extreme weather events. Data from a rural household survey (n = 240) conducted in Mahajanga II, a district in northwest Madagascar, is used to (1) identify extreme weather impacts upon smallholder farmers from 2000-2015 and assess how socioeconomic and geographic factors influence these experiences, and (2) explain how farmers' hazard experiences influence local perception of forest regulatory services (specifically flood control and moderating the flow of excessive sediments and debris flow onto farmlands).

The chapter begins with a review of the impacts of extreme weather events on smallholder farmers. This is followed by a description of the study site, including an explanation of climate, agricultural production and forest conditions present in the region, the farmer characteristics from the case study and data analysis methods used. Finally, the empirical analysis focusing on the hypothesis (stated above) is presented.

5.2 Weather extremes and impacts on rural households

Extensive literature on vulnerability to hazards dating back to the seminal work by Gilbert White (1945) shows that hazard impacts are determined not just by the type, magnitude and duration of hazard, but also by the susceptibility of individual households to those hazards (Burton et al. 1968, O'Keefe et al. 1976, Wisner and Luce 1993, Mustafa 1998, Pielke Jr and Downton 2000). Susceptibility is created by many factors, including physical proximity or exposure to hazards (Pelling and Uitto 2001), types of elements exposed (Changnon et al. 2000, Kron 2005, Messner and Meyer 2006), the presence or absence of hazard mitigation technologies, for example flood barriers, the level of preparedness for hazards (Cutter et al. 2003, Tompkins 2005, Grothmann and Reusswig 2006) and the differences between households driven by poverty, unequal access to resources including information, and wider social structures (Mustafa 1998, Wisner et al. 2004, Eakin and Bojorquez-Tapia 2008). Thus, different levels of susceptibility influence the way in which neighbouring households experience the same hazard and can lead to very different hazard outcomes. In this section, we consider the factors that influence smallholder farmers’ experiences of storm hazards.

Elements of susceptibility such as exposure to climatic shocks create both direct impacts, for example, drought and flood damage to crops, and indirect impacts such as crop diseases and pests caused by unusually humid conditions, water logging, warmer temperatures or other environmental variables, in turn causing increased months of food insufficiency for agricultural households (Reardon et al. 1988, Misselhorn 2005). The direct effects of climate shocks are manifested through extreme weather events such as cyclones, tropical storms, unusually intense rainfall, floods, high winds and persistent droughts, all of which exacerbate the stresses and shocks rural households live with in most tropical developing countries (Reardon and Taylor 1996). Excessive rain during a short time period and changes in the distribution of rainfall during the wet season are factors responsible for damage to crops in many regions of the world (Mertz et al. 2009). According to studies conducted in South Africa and Ethiopia (Bryan et al. 2009), farmers report experiencing changes in the onset of rainy season, abrupt stop to rains during the normally wet months, high winds, frost and warmer temperatures. In Nepal, Gentle et al. (2014) find that the majority of the study participants experienced “erratic rainfall” followed by frost, landslides and erosional gullies. In northwest Ghana and Nigeria, while emphasizing the seasonal nature of the savannah, farmers report more variability in the onset of rains and the subsequent distribution and end of the rainy season (Tambo and Abdoulaye 2013, Nyantakyi-Frimpong and Bezner-Kerr 2015).

Such weather shocks cause damage to rural livelihoods through multiple channels, which are often indirectly related to the hazard, and by affecting multiple household elements. Crop production under rain-fed conditions is especially sensitive as excessive rainfall or droughts have a negative impact on crop yield (Rosenzweig et al. 2001). Unusually wet years can cause crop yield declines due to pests and diseases, floods, soil erosion and water logging, while drought can cause crop declines due to plant stress, lowering resistance to diseases, and increased numbers of insect vectors and diseases (Rosenzweig et al. 2001). Unpredictable rainfall or shifts in the onset of rains lead to delayed planting of staple crops such as rice, which in turn increases the sensitivity of crops to climate stress, or they may lead to the farmers changing the sequence of crop planting, such as dropping groundnuts in the case of Northwest Ghana (Nyantakyi-Frimpong and Bezner-Kerr 2015). Tropical cyclones in Madagascar are often associated with widespread agricultural damage through the loss of shelters where grain stocks are stored, damage to irrigation canals, damage to farmlands from siltation or mudslides, and increased instances of human disease, inaccessibility through damage to roads and markets, and damage to houses, schools and medical facilities (Rakotobe et al. 2016). Thus, susceptibility can arise from exposure to climatic events that affect food production, health and income, and can cause loss of life and property.

In addition, smallholder farmers, whose agricultural activities include subsistence production and production concentrated on the market, are part of a socio-ecological system characterized by its exposure to both climate and non-climate stressors (Morton 2007). Both of these factors influence the susceptibility of individuals, communities and countries to the impacts of hazards. O’Brien et al. (2004) and Adger (2006) identify that poverty and other developmental challenges stemming from change in institutional policies, lack of governance and insecurity caused by political upheavals create an underlying level of vulnerability that makes households susceptible to any shock. For example, Eakin (2005) examines how changes in agricultural policies driven by market liberalization and globalization define farmers' climate risk management strategies across three rural Mexican communities characterized by a mix of subsistence maize production, adoption of market oriented cash crops and income diversification, finding that first and foremost farmers organize their livelihood strategies to confront institutional change. Farmers' susceptibility to climatic shocks, such as extreme frosts, and their ability to manage climate risks are consequently a function of the livelihood strategies adopted to deal with national policy decisions in Mexico.

By all indications, smallholder farmers are some of the most vulnerable segments of society, exposed to increased climate variability and its impacts. It is therefore important to understand how experiences of weather extremes and associated hazards influence farmers' perspective of the role of forests within the landscape in regulating the consequences of hazards such as floods, mudslides, debris flow and erosion. The next presents the methods applied to conduct such an analysis, the results of data analyses and conclusions that can be drawn to elaborate the relationship between forest-edge famers and these natural habitats.

5.3 Materials and Methods

This study has two objectives. To deliver Objective 1 of identifying extreme weather impacts upon smallholder farmers, a typology of wet season hazards experienced by farmers in the case study region over 2000 – 2015 was created. To deliver Objective 2 of explaining how farmers' hazard experiences influence perception of forest regulatory services, key variables, such as the proportion of crops lost and farmers' perception of regulatory services provided by forests in the landscape, were represented spatially in order to map and discuss variation in responses across households. Thereafter, regression models were created to a) identify factors influencing household vulnerability to hazards, and b) evaluate whether different classes of hazard impacts are more or less likely to be significant predictors of farmers' perception of flood control and regulation of sedimentation and debris flow by forests. For the evaluation of the significance of different types of hazards a spatial flood hazard rank derived from a global flood model (GFM) (Sampson et al. 2015) was used as one of the independent variables, in addition to those derived from the household surveys.

The following section describes the study area including precipitation patterns over western Madagascar in the recent past (1981 - 2015), followed by methods for data collection and analyses, and a summary of household characteristics derived from descriptive statistics.

5.3.1 Study area

This research took place in Mariarano commune in the northwest district of Mahajanga II in Madagascar's Boeny region (Fig. A4.2). Data collection involved household surveys, participatory mapping and key informant interviews in seven villages across two "*fokontany*", the smallest administrative unit with elected officials, specifically three villages in Mariarano and four in Antanambao. Antanambao and Mariarano[8] *fokontany* occupy a surface area of 400 km^2 (40,000 ha) with a total population of 3539 (Chapter 3, Fig. 3.1). The two *fokontany* present an interesting contrast: Mariarano is characterized by a forest cover trajectory that shows positive gains, and Antanambao is faced with the opposite situation (PGM-E and GOM 2013). Out of the 492 km^2 of seasonally dry deciduous 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). This reflects a broader trend across much of Madagascar's dry forest habitats with over 18 % deforested between 1980 and 2000 (Miles et al. 2006). Notwithstanding this loss, dry forests across the country are important for livelihood generation as sources of fuelwood, charcoal production and food security, for example, the use of the forests to keep small ruminants and the consumption of tenrec (*Tenrec ecaudatus*), a small mammal; meat from which can reach 0.75 kg per month per person (Waeber et al. 2015).

[8] Mariarano Commune has eleven *fokontany*, with the *fokontany* Mariarano also the "chef lieu" of the commune. The two *fokontany* that form the case study here have the largest and second largest population within the commune. .

The farming schedule is typically adapted to the seasonal calendar to coincide with the onset of the rainy season in November. Farmers in this area practise rain fed rice production as their primary livelihood and thus are highly exposed to extremes and variability in precipitation. Rainfall levels vary significantly across an east-west gradient in Madagascar where a nearly year-long wet season in the east contrasts with a distinct dry season for the west coast. Mahajanga II has a distinctive wet season from November to April. Figure 1 shows variability in monthly rainfall amounts received, showing large intra-annual variability in the amount of rainfall received during the typically wet months of November to March (Fig 5.1a), and the inter-annual variability in precipitation from 1981-2015 (Fig 5.1b) using data from the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) (Funk et al. 2015). In addition to inter annual climatic variability, tropical storms and cyclones are a frequent occurrence during the wet season with an estimate 2.9 cyclones annually on average making landfall in Madagascar over a 66 year period from 1948-2014 (Fitchett and Grab 2014). Inter-annual variability in rainfall seen in Fig 5.1b for the case study region is usually associated with cyclone effects.

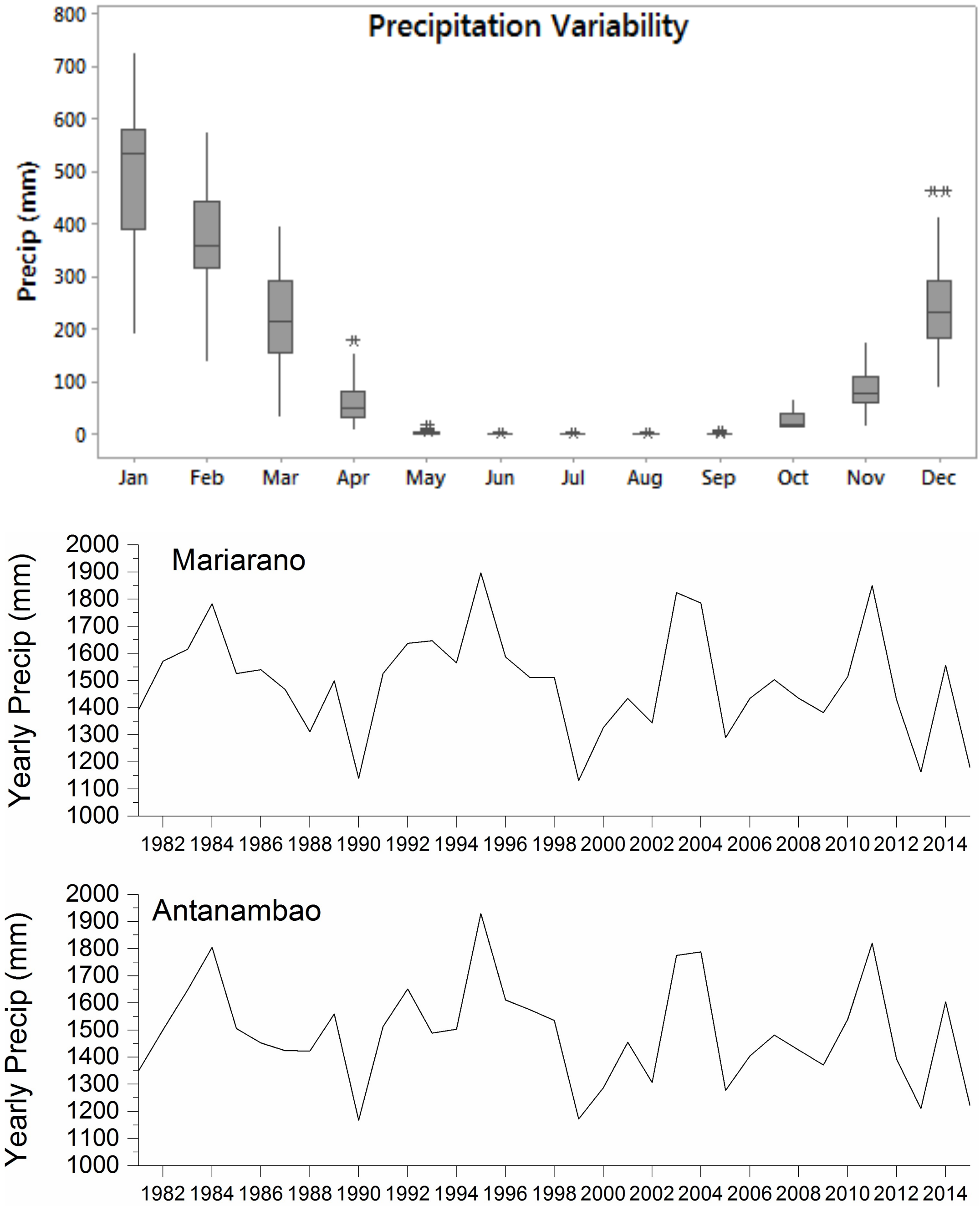

Figure 5.1 – Top diagram 5.1 a: Variability in monthly rainfall over a 25 year period from 1981-2015 in Mahajanga II's Mariarano Commune; Bottom diagram 5.1 b: Inter-annual variability in rainfall in the two case study fokontany from 1981-2014 (Funk et al. 2015)

5.3.2 Data collection

The study involved household surveys, participatory mapping with focus group discussions and key informant interviews. Data were collected during two phases of fieldwork: in September 2014, and a second period of five months from May to October 2015. Malagasy field assistants were employed to carry out the pilot test of the survey instrument, the full household survey, and the interviews. As there is no list of households living in each village, the electoral list obtained from the *fokontany* chief provided the sampling frame. The final sampling frame included household heads between the ages of 26 -70 years old. Many questions in the survey deal with identification of hazard experiences or lean season over a period of five years, thus, 26 years was set as the minimum age of the household head, in order to ensure that the 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). The upper age limit was set at 70 to ensure only those who were still actively farming were interviewed. Within these constraints, households were selected randomly using a random number generator. A total of 240 household heads, 146 from Mariarano and 94 from Antanambao were interviewed. In Madagascar, as in many traditional African societies, household heads are usually male, thus the majority of the respondents were men, other than in situations with single women or female-headed households. Respondents were asked questions on household demographics and income generation, and specific questions on experiences of climate variability and extremes, the types of hazards experienced, damages to crops and estimates of proportion of rice crop lost. Within the section on forest uses, we included two statements to gauge respondents' perception of the regulatory role of forests, to which they could respond yes or no (See full questionnaire in Appendix D).

To identify spatial patterns in hazard impacts and damages suffered by families in the two *fokontany* GPS points were collected. These points reflect the location where the interviews were conducted, which were at an individual's farm, the market in Mariarano or the main village centres where people had their houses. While the GPS points do not necessarily reflect the precise location of farms, they are a close enough approximation of households' stable abode and location in the relevant village, thus these points are able to provide a spatial representation of the experiences and attributes of individual respondents.

5.3.3 Methods for data analysis

To identify relationships between hazards experienced, damages to livelihood sources and local perceptions of the flood control and / or sedimentation and debris flow reduction role played by forests in the landscape, a mix of multivariate statistical analysis and spatial representation was applied using data from household surveys. Information gathered during key informant interviews and participatory mapping during focus group discussions provided an explanatory context for the survey results. Data triangulation was achieved by asking discussion groups about areas more or less exposed to different types of hazards (Fig. 5.2 a and b). Information from focus group discussions was particularly useful in enabling the researcher to understand local perception of risk, identify areas exposed to different types of hazards and to gain an insight into the evolution of land cover change based on local knowledge. An additional objective was to evaluate the match between reported experiences of hazard impact classes and the outputs of a global flood model (GFM) (Sampson et al. 2015). To integrate results from a biophysical flood hazard model a hazard rank was assigned to each of the household's georeferenced location points. A hazard ranking created at 90 m resolution (ibid.) was used, which partitions hazards from 1 (low risk, wet in 1 in 1000 year fluvial and flash flood simulation) to 4 (very high risk, wet in 1 in 5 years fluvial floods). This variable is referred to as as "GFM hazard rank", and used as one of the explanatory variables.

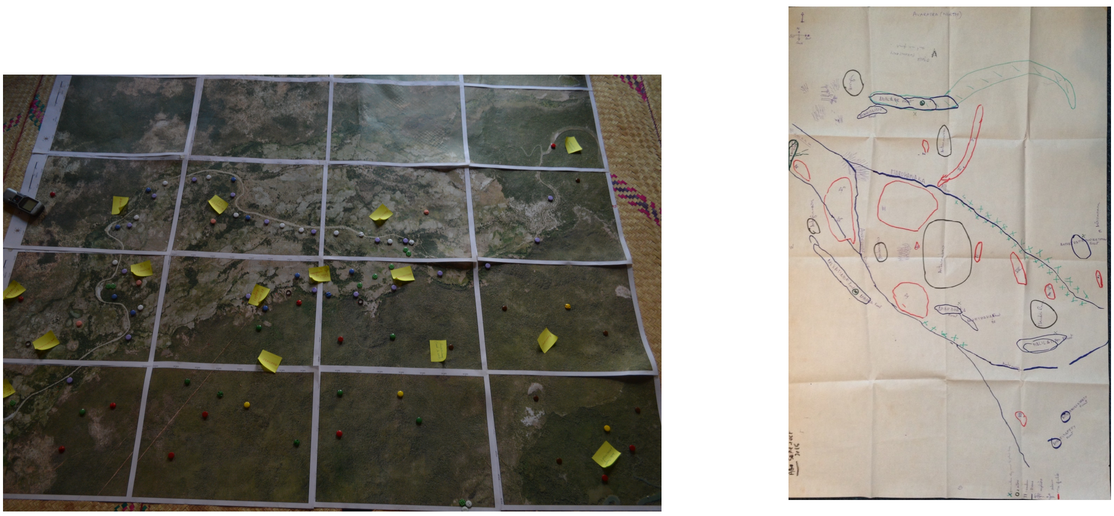

Figure 5.2 - Methods for participatory mapping: a) Mariarano fokontany, using a mosaic of aerial photographs from 2007 to represent the land area covered by Mariarano *fokontany* b)Antanambao *fokontany* – hand drawn with focus group participants.

To identify the agricultural hazards experienced during the wet season in western Madagascar a subset of twelve hazards experienced locally was created after discussions with key informants and field observations during September 2014 and May 2015. Respondents were asked to note yes/no to relevant hazards experienced from this list, where possible indicating the year in which these occurred. These hazards include incidences of farmlands being inundated with standing water, the formation of mudslides and erosional gullies, siltation for short time periods or permanent degradation of fields by sand deposition, high winds, fast flowing water, sediment or debris flows and damage to rice crops caused by insect pests. In addition to hazards directly affecting fields, respondents were asked about flood waters blocking access by paths to the nearest village centre with medical facilities and markets, and flood or wind caused damage or destruction of the family's abode.

To identify possible groups of hazard types, hierarchical cluster analysis was used on these twelve binary variables using squared Euclidean distance as a measure of similarity and Ward's method for clustering (Köbrich et al. 2003). The resulting hazard impact categories are:

- Type I: Flood inundation and insect infestation
- Type II: Damage from erosional gullies
- Type III: Siltation of fields
- Type IV: High winds, fast flowing water and sediment laden water
- Type V: Lack of access to markets, medical clinic and secondary school
- Type VI: Damage or destruction of primary abode

To identify intensity of damages suffered as a consequence of experiencing one of the above hazard classes an aggregate indicator was created, called the "*intensity of damages*" combining responses to questions on whether the household experienced yield loss of the rice crops, loss of other crops, like maize and livestock loss (score 0-3), from the most recently experienced heavy rainfall linked hazards. A variable quantifying the proportion of rice crop lost was based upon the respondent's recall of the proportion by which rice yields were reduced during the most recent hazard event.

Correlation analyses were performed to identify relationships between socioeconomic variables associated with individual households and experiences of hazards, and between the hazard classes and the intensity of damages and proportion of rice yield lost. In order to test the study's hypothesis that the hazards and damages suffered due to extreme weather in the wet season influence local perception of the flood and sedimentation mitigation role of forests in the landscape, four variables were used as possible explanatory factors: i) the GFM hazard rank, ii) the six hazard types from the cluster analysis, iii) intensity of damages and iv) proportions of rice crop lost.

5.3.4 Household characteristics in study area

Socio-economic and demographic data from household surveys described a population living with a basic set of human and financial assets, utilizing rain fed rice production augmented with varying levels of forest product harvests and production of maize, cassava, vegetable greens, fruits, and livestock. On average, 42 % of household members were under 15 years of age and 52.5 % were adults between the age of 15 and 65. Main agricultural production was focused on the staple food crops of rice, maize and cassava, with 59.6 % of the respondents producing all three and 10 % growing only rice. These results are similar to those of studies in other parts of Madagascar (Harvey et al. 2014, Poudyal et al. 2016) and in other regions of the world (Amekawa et al. 2010, Asfaw et al. 2013). Staple crop diversity as indicated by the production of cassava and maize was widely used as a strategy for smoothing consumption during the wet season, which coincides with low food stores and is known locally as the "*silaony*". Diversifying into fruit crops, livestock and wage labour[9] were other commonly utilized livelihood strategies, also seen across smallholder communities in tropical developing countries. Such households are typically vulnerable to a host of climate and non-climate stressors (Eakin 2005). Cattle theft is now highly prevalent in parts of Madagascar and in our study only about 6 % of the respondents owned more than 40 heads of cattle, with 30 % no longer owning any cattle. Approximately 24 % of the respondents augmented their household labour input for farming with help from others in the village. This non-family labour was usually paid in

[9] Wage labour refers to working for wage income on somebody else's farm, finding short term or seasonal income earning opportunities in neighbouring communes or in the nearest city of Mahajanga.

the form of cash and/or a portion of the rice harvest, or obtained through "*fokonolona*" – the practice of community members helping each family by turn. Mean scores on attitudes towards the importance of forests for water regulation and agricultural production showed that a majority of respondents regarded local forests as important for water provision, availability, and agricultural production. Of the three possible rice crops in the area, over 90% of respondents grew rice during the rainy season (known as the *asara* crop). 56.5 % reported growing a second rice crop of *jeby* in the dry season using irrigation channels and harvested in December, and 30 % reported practicing *ahitrahitra*, the short May-August crop.

Table 5.1 - Demographic and socio-economic characteristics of households and expected influence on hazard experiences, intensity of damage and crop losses reported

	Variables	**Units**	**Mean/ Mode**
a	*Demographics*		
	Age of household head	Years	42.40
	Household Size	Number	5.40
	Number adults 15 -65 years old	Number	2.65
	Number of food insecure days	days	57.00
b	*Assets*		
	Education, household head *(no education (0), primary school (1), secondary (2), tertiary (3) or university (4)*	Years	1
	Cattle ownership *(0 = no cattle, 1 = 1-10, 2 = 11-20, 3 = 21-30, 4 = 31-49, 5 = 50-80)*	category scale	1
	Number of rice harvests/year	Number	2.10
	Family farm labour input	Number	2.90
c	*Agricultural production*		
	Years in farming*	number	22.98
	Number of staple crops grown (1-3)	number	2.49
	Diversity of other food crops/trees	number	4.65
	Asara rice yield (amount harvested/seeds used)	Kg	167.76
	Jeby rice yield	Kg	110.89
	Ahitrahitra rice yield	Kg	59.54

5.4 Results

In this section I report on analyses of household data and spatial mapping to present results on: Objective 1: identify extreme weather impacts upon smallholder farmers, and assess how socioeconomic and geographic factors influence these experiences, and Objective 2: explain how farmers' hazard experiences and the global flood model derived flood hazard rank ("GFM hazard rank") influence local perception of forest regulatory services (specifically flood control and moderating the flow of excessive sediments and debris flow onto farmlands).

5.4.1 Household experiences of extreme rainfall events and hazard impacts: hazard impact types, damages, and spatial representation

A majority of respondents across both *fokontany* reported having experienced an extreme rainfall event[10] (93.2 %), changes in the onset of the rainy season (89.7 %) and changes in the distribution of rains over the expected rainy season (72.1 %) during the period 2000-2015. These results are similar to those seen in several regional studies within Africa on farmers' experiences and perception of shifts in seasonality and the predictability of the "normal" patterns of weather (Mertz et al. 2009).

After identifying perceptions of climatic variability, respondents were asked to evaluate how they were physically impacted during such events. The physical hazard impacts most prevalent in the two *fokontany* were: inundation of rice fields followed by crop damage from high winds, excessive sediment load flowing onto fields, the formation of erosional gullies, rapid flow of water capable of washing away young rice crops, and siltation of farmland or parts of it, rendering its use for rice impossible either in the short term or in the long term or leading to permanent abandonment. Households also reported having problems with insect damage to rice crops, lack of access to the market, medical clinic and secondary schools in Mariarano, and damage or destruction of houses during times of extreme weather.

These responses were used in a hierarchical cluster analysis to identify statistically determined groups of hazard classes (Table 5.2). The resulting six distinct hazard classes are supported by our expectations based upon our knowledge of the local context and theoretical judgement. Next, we identified intensity of damages suffered due to these hazard experiences for the most recent event, and for those respondents who estimated

[10] Respondents were asked whether they had experienced "rainy season with more intense / higher than usual rains"

having lost part of their rice crop yield we identified the proportion of rice yield lost. Damage to rice fields was reported by over 60 % of the population and damage or loss of other crops was reported by 7.9%.

Reported hazard experiences correlated positively with intensity of damages and the proportion of rice loss estimated by farmers, with the exception of those who experienced siltation of their fields (Hazard class III in Table 5.2). This category of hazards did not show any significant relationship with consequent reporting of damages to different crop types and proportion of rice yield lost (See Table B5.1). The global flood model derived hazard ranking was negatively correlated with the risk of siltation, but not significantly related with the other hazard types.

Table 5.2 - Hazard impact experiences, proportion of households experiencing each and clustered typology of hazard impacts (N=239)

Hazard Experiences	*Proportion of sample answering "Yes"*	*Hazard Impact Types*	*Unit*
Flood inundation of ricefields sufficient to cause damage to crops	58.60%	Type I	Scale 0 - 2
Insect pest infestation brought on by intense rainfall during short periods	76.20%		
Erosional gullies that damage parts of fields	37.20%	Type II	0/1
Siltation of fields for short time - can use again next year	14.20%	Type III	Scale 0 - 3
Siltation of part of fields for long term	12.60%		
Siltation of ricefields causing permanent abandonment	3.30%		
Fast moving water, capable of washing away rice crops	34.70%	Type IV	Scale 0 - 3
Sediment and debris laden water	41.00%		
High winds	44.00%		
Lack of access to market, secondary school and medical clinic in Mariarano village during heavy rains/storms	57.60%	Type V	0/1
Damage to house or dwellings	36.40%	Type VI	Scale 0 - 2
Destruction of house or dwellings	26.20%		

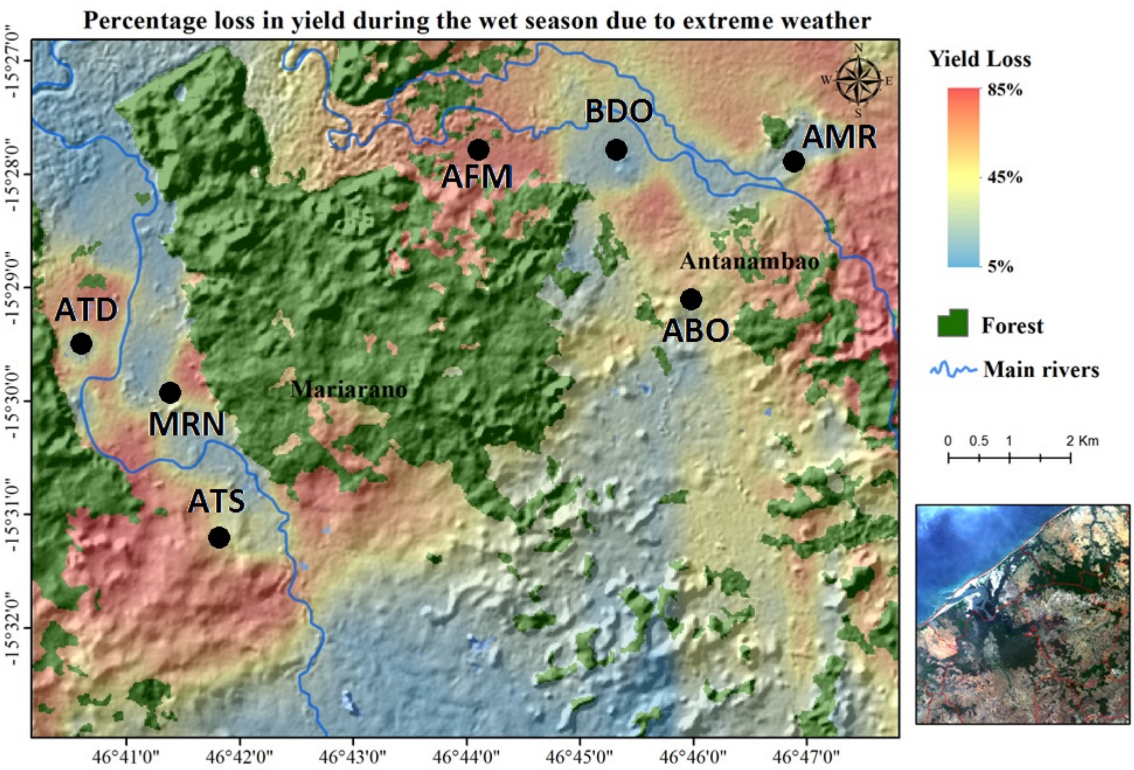

Figure 5.3 - Spatial patterns of estimated percentage of rice crops lost across the two *fokontany.* The villages surveyed are: Antanandava (ATD), Antsangabe (ATS), Mariarano (MRN), Antafiameva (AFM), Ambondro (BDO), Antanambao (ABO) and Antanamiarna (AMR).

5.4.2 Socio economic and geographic factors influencing hazard experiences, intensity of damage and loss of rice crops

Demographic and socio economic variables can have significant associations with the experience of hazards, and consequent impacts and damages (Mustafa 1998). Data collected in this study showed significant associations for respondents facing a higher number of food insufficient days with experience of erosional gullies on farm plots in Antanambao and with having their house destroyed or damaged in Mariarano (Table 5.3). Respondents experiencing floods and insect damage, erosional gullies, siltation damage to fields and damage or loss of house had a higher staple food crops score in Antanambao. These results are supported by other studies showing the importance of diversification of staple food sources as a risk minimizing strategy employed by rural households (Vedeld et al. 2007, Herrero et al. 2014). Gully erosion is usually caused by agricultural practices such as continuous cropping without fallow periods, building irrigation channels from soils that can expand over time and deteriorate into gullies by surface water runoff, and overgrazing (Mashi et al. 2015). All of these practices are observed in our study site. Table 5.3 reports results from this correlation analysis. In both Mariarano and Antanambao *fokontany* those who engaged in wage labour were more likely to have experienced agricultural damages from high winds, rapid water flows and sedimentation on their own fields (Table 5.3).. We found no significant relationship between education levels and ranking on the GFM flood risk or any of the other six hazard impact classes.

Differences in the geography of the two *fokontany* and the relative positions of the seven villages with respect to distance to nearest forest fragments, rivers and the village of Mariarano for market access, influenced the observed relationships. For Mariarano *fokontany,* distance from nearest forest fragments showed a positive relationship with with problems accessing the market, medical clinic and school in the village of Mariarano (hazard impact type V). Siltation (hazard impact III) was less likely with increasing distance to forests. Households further away from forest fragments had a significantly higher GFM hazard rank in *Mariarano fokontany* and this variable increased with decreasing elevation and slope values. Distance to the river showed a significant relationship with accessibility, with increasing distance from the river, households had more problems of accessibility (Table 5.3).

In contrast, in Antanambao, households nearer to the rivers were more likely to experience the hazards of siltation (hazard impact type III) or damage from fast flowing waters, excessive sedimentation or high winds (hazard impact type IV) because of their physical location in the floodplains, while decreasing distance from forests, associated significantly with higher slope values, reduced the likelihood of having experienced hazard impact types III and IV. Also in Antanambao, higher slope values were also significantly associated with households having experienced erosional gullies on their fields. Geographically, while gullies are usually associated with hillsides and steep slopes, it can form on land with slopes as low as 1% particularly on dispersive soils such as highly sandy soils (Valentin et al. 2005), such as those found in northwest Madagascar in areas occupied by the dry forest biome.

Table 5.3 - Socioeconomic and geographic variables and correlations with the six different hazard types and GFM hazard rank.

Mariarano Fokontany ***N=146***	**GFM Hazard Rank**	**Hazard Type I** ***Floods & Insects***	**Hazard Type II** ***Erosion Gullies***	**Hazard Type III** ***Siltation***	**Hazard Type IV** ***Rapid water flow, high winds, sedimentation***	**Hazard Type V** ***Lack of access***	**Hazard Type VI** ***Damage/ destruction of homes***
Socio economic Variables							
Cattle owned	.226**		.221**	.227**			.199*
Wage labour income					.223**		
Number of staple crops grown						.201*	.226**
Number of other crops grown				.243**			.176*
Household size							.196*
Number of under 15 years						.164*	
Number of days with insufficient food							.182*
Location Variables							
Distance to river						.217**	
Distance to forest	.483**			-.218**		.212*	
Slope	-.540**						
Elevation	-.487**						
Antanambao Fokontany *N = 94*							
Socioeconomic Variables							
Wage labour income					.243*		
Number of staple crops grown		.232*	.209*	.224*			.369**
Number of other crops grown			.218*				.222*
Household size	.335**						.226*
Number of under 15 years	.355**						.238*
Number of rice crops harvested/year		.244*					
Yield of second rice crop (jeby rice)	.255*						
Number of days with insufficient food			.263*				
Location Variables							
Distance to river				-.231*	-.233*		
Distance to forest				.224*	.261*		
Slope	-.250*		.255*				
Elevation	-.203*						

5.4.3 How do prior experiences of hazards and ensuing damages influence the perceived storm hazard regulation derived from forests?

This section reports on the results of logistic regression models constructed using the GFM hazard rank, the four hazard category types that directly affect cropland or standing crops (Hazard Types I, II, III and IV), the intensity of crop damages suffered and the percentage of rice crop lost as explanatory variables to assess how these relate to farmers' perceptions of storm hazard regulation by forests in the catchments. The two dependent, binary variables that were used as a proxy to gauge farmers' perceptions were whether respondents perceived a moderating effect of local forests and raffia wetland remnants on the flood levels in their fields and whether they perceived local forest could reduce the amount of debris flow and sedimentation flows in the aftermath of heavy rains.

5.4.3.1 Hazards and damages experienced as predictors of forests' flood control belief

Results from the logistic regression model show that the three hazard experiences that are seen as significant predictors of holding a positive view of the role of forests in reducing flooding were experiencing: i) erosional gullies on farmlands, ii) rapidly flowing waters, high winds, and excessive sediment laden water, and iii) consequent damages to crops, "intensity of damages" (rice or others) (Table 5.4). While erosional gullies and experiencing damages to one or more crop types increases the odds of viewing forests and the surrounding vegetation as beneficial for regulating flood waters, our model indicates reduced odds of perceiving this relationship if respondents have experienced the effects of high winds, excessive sediment laden and rapidly flowing water.

5.4.3.2 Hazards and damages experienced as predictors of sedimentation and debris flow regulation belief

Erosional gullies and estimates of rice crop lost both increase the odds of farmers' holding a positive perspective on the role of forests and raffia remnants in reducing the flow of sediment and debris onto their fields. However, importantly, having experienced the hazards within Hazard Type IV, those of rapid water flows damaging young crops, heavy sediment laden water and high winds reduces the odds of holding this view ($p = .059$) by about 30 % (Table 5.4). In order to examine differences between the two *fokontany,* we investigate this relationship further to find that this inverse relationship with hazard class 4 is significant in Mariarano for both dependent variables, with the hazard of erosional gullies acting as a positive predictor (Supplementary Table 3). In figures 5.4 and 5.5 we show the spatial patterns for perceptions of the role of forests in flood control (Fig 5.4) and role of forests in controlling excessive sedimentation and debris flow (Fig. 5.5).

Table 5.4 - Significant predictors of respondents' beliefs that forests contribute to flood regulation or reduce sedimentation and debris flow

	B	S.E.	Sig.	Odds ratio
Dependent: Forests and flood regulation belief				
Erosional gullies	0.473	0.157	0.003	1.605
Rapid water flow, sedimentation and high winds	-0.369	0.168	0.028	0.691
Intensity of crop damages suffered	0.321	0.162	0.048	1.378
Constant	0.443	0.146	0.002	1.557
Dependent: Forests and sedimentation, debris flow regulation belief				
Erosional gullies	0.464	0.182	0.011	1.59
Rapid water flow, sedimentation and high winds	-0.333	0.177	0.059	0.717
Percentage of rice crop lost	0.38	0.18	0.035	1.462
Constant	1.15	0.169	0	3.158

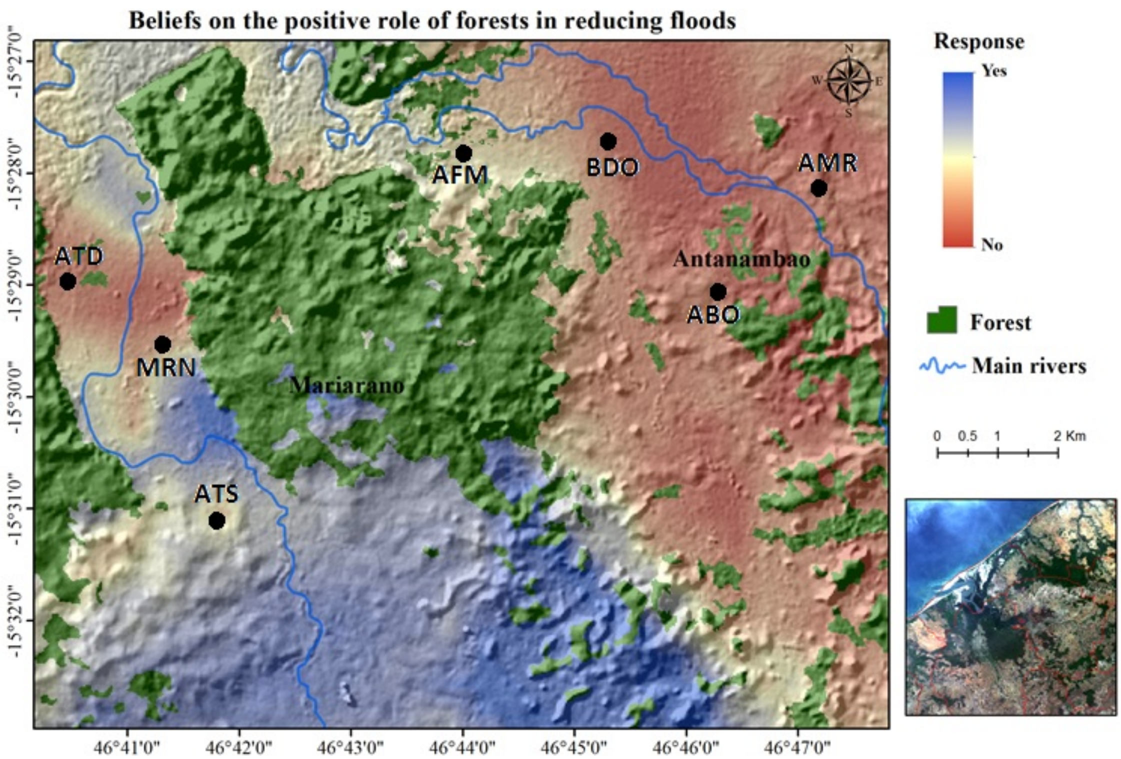

Figure 5.4 - Location of forests and distribution of the belief that forests reduce floods across the two *fokontany,* with village codes as follows: Antanandava (ATD), Antsangabe (ATS), Mariarano (MRN), Antafiameva (AFM), Ambondro (BDO), Antanambao (ABO) and Antanamiarna (AMR).

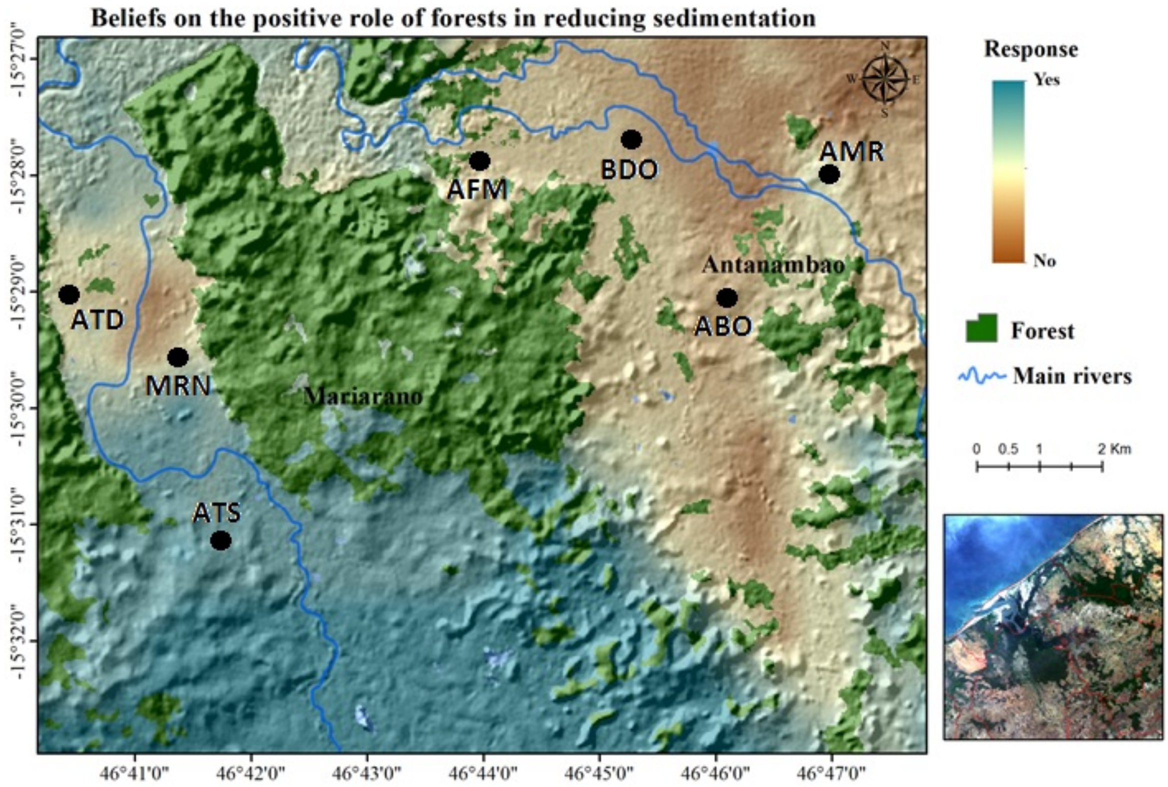

Figure 5.5 - Location of forests and distribution of belief in the regulatory function of forests in reducing debris flow and sedimentation across the two *fokontany,* with village codes as follows: Antanandava (ATD), Antsangabe (ATS), Mariarano (MRN), Antafiameva (AFM), Ambondro (BDO), Antanambao (ABO) and Antanamiarna (AMR).

As seen from Figure 5.4 and 5.5, there were clear distinctions between the two *fokontany* in their beliefs about the potential for forests to regulate storm hazards (flooding, sedimentation and debris flow). The light red-brown colour in Mariarano reflects the responses of those who had experienced hazard Type IV (rapid water flows, high winds and sediment heavy waters), reducing the odds of their holding a positive view of the role of forests in controlling floods. The propensity to hold positive beliefs is seen to be closer to the edge of the forests (light yellow colour). During the focus group conducted in Antsangabe village (marked in Fig 5.4 and 5.5), in Mariarano, several participants discussed the increasingly shallow and wider flow of the river, with increasing amounts of debris, sand and sediment blamed for this and suggested that the loss of forests and riverside vegetation upstream of the *fokontany* was responsible for this situation.

5.5 Discussion and conclusion

The research presented in this chapter contributes to the explanation of how smallholder farmers experience storm hazards and how these experiences influence their perception of the regulatory functions of forests. The main hypothesis for this study was that there is a complex relationship between climatic shocks, hazard experiences of forest edge dwellers and forest use, notably, that previous experiences of hazards influence people's perception of the role of forests in reducing / moderating the impact of such hazards, which in turn leads to greater support for sustainable forest management.

The results point to direct associations between different socioeconomic household factors and hazards impacts and damages. Two main types of hazard impact types are worth highlighting: gully erosion, and the hazards of high winds, rapidly flowing water and sediment laden water affecting crops in fields. In the first case, experiencing gully erosion was related to longer periods of food insufficiency in a year for Antanambao *fokontany* (a variable associated with seeking off farm or hired labour wage income). All of these practices are observed in this study site. This is an important finding that demonstrates the differential effects of hazard exposure on households with different socioeconomic characteristics, and corroborates studies linking households' vulnerability to socio economic attributes in addition to physical exposure (Mustafa 1998, Eakin and Bojorquez-Tapia 2008). Gullies are linked to reduced crop yields and farmland, increased labour input to cultivate land, accelerated draining of water leading to aridification and localized erosion causing loss of soil fertility and downstream effects (Valentin et al. 2005, Mashi et al. 2015).

In relation to the second set of hazard impacts (hazard impact type IV: high winds, damage to rice crops from fast flowing or sediment laden water), this research shows a direct relationship with increased instances of relying on seasonal wage labour to meet household food needs. Physical factors influence the exposure of households to these hazards. Proximity to rivers in one of the *fokontany* directly affects the likelihood of being impacted by this hazard type, however these experiences are not seen to impact food availability, unlike the relationship with hazard type II, gully erosion. Proximity to forests is significantly related to experiencing this hazard type, with those closer to forest fragments less likely to experience such hazards and holding a positive perception of forest's role in reducing sedimentation, debris flow and/or flooding. While the flood hazard model ranking shows the expected relationships with physical location factors such as slope, elevation and distance to forests, there is almost no relationship seen between having higher exposure to fluvial and pluvial floods and the actual experiences of hazards reported by the interview respondents. A possible explanation of this lack of relationship is that locations that naturally have a very high flood hazard are more resilient to flooding by having adapted their production systems over generations.

Significantly, these results confirm the study hypothesis of a complex relationship between these hazard experiences and damages suffered and farmers' perception of storm hazard mitigation by forest patches in the catchments. The results how that respondents affected by gully erosion are clearly predisposed to view forests as important moderators of flood levels and the amount/nature of debris flow and sediment flowing onto their lands. Similarly, respondents affected by fast flowing waters, high winds and sedimentation (hazard type IV) hold the opposite views. The study's results also point to a direct association between damages to a greater variety of staple crops or higher estimated losses of rice crops suffered and holding a positive perception of flood control benefits or sedimentation and debris flow reduction. This difference can be explained to a certain extent based upon studies that have shown deforestation as one of the factors responsible for causing erosion gullies in similar settings as this (Mashi et al. 2015), thus one can argue that farmers have seen areas without vegetation around their farms to be more susceptible to high runoffs, mudslides and gully formation, and are thus making this association. The fact that experiencing fast flowing waters, high winds and sedimentation (hazard Type IV) reduces the odds of viewing positive interactions between the presence of vegetation and reduced flooding and reduced sedimentation can be attributed to the reality that many people have farms that are surrounded by other farms, not in close proximity to the forest edges, thus if these farms experience rapid flows of water and sedimentation, their owners are more likely to blame it on rains. Thus, some types of hazard impacts are more likely to influence the perception of forest benefits for flood and sedimentation control than others, and to do so in opposing ways.

This is one of the few studies that has characterized the nature of some of the physical hazards that translate into risks to agricultural production and consequently influence perceptions of forest regulatory services held by smallholder farmers in western

Madagascar. In turn, this research contributes to the body of work on understanding local scale interactions between biophysical processes such as flooding, sedimentation, erosion and gully formation, forest cover and the perception of these relationships held by farmers on the forest frontier. In conclusion, there is more targeted research that needs to develop and/or clarify the links between different hazard experiences, acknowledged storm hazard regulation by forests and how these perceptions may or may not impact decisions on support for forest management by smallholder farmers.

Chapter 6: Forest ecosystem services derived by smallholder farmers in northwest Madagascar: Storm hazard mitigation and participation in forest management

This chapter is *in press* as:

Radhika Dave, Emma L. Tompkins, Kate Schreckenberg. 2016. Forest ecosystem services derived by smallholder farmers in northwest Madagascar: Storm hazard mitigation and participation in forest management. *Forest Policy and Economics.*

6.1 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. 2014a). 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 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, this thesis uses 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 chapter, using an ecosystem services' lens, household surveys in seven villages in Madagascar were used 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 6.1). I 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.

This chapter is structured as follows: first a description of the study area is provided, followed by the methods of data collection and analyses performed, finally, the chapter is focused on answering the following 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?
- 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)?

The chapter then presents 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. The chapter concludes 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.

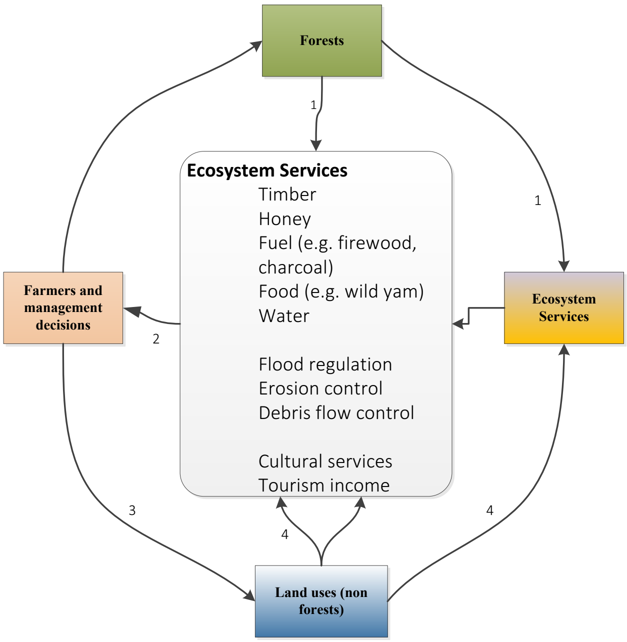

Figure 6.1 - The pathways of ES flows from forests (1) to farmers include the use of raw materials, e.g. timber, honey production, fuelwood, food, tourism income and recognition of regulatory services such as flood and erosion control (2). Such uses and benefits have consequent land use impacts (3) which feed back into ES flows and benefits to farm households and influence forest management decisions (4). The research questions in this chapter focus on the uses and perceived regulatory services derived by farmers and linkages to forest management decisions.

6.2 Study Area

The study area for this problem is in the Boeny region of northwest Madagascar as described in Chapter 5, 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 centre). Rice farming dominates agricultural production, which can be typically characterized as small-holder subsistence, primarily rain-fed, farming. Maize and cassava form the secondary 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.

This 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 as also described in Chapter 3 and 5 of this thesis. 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. 6.2). 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.

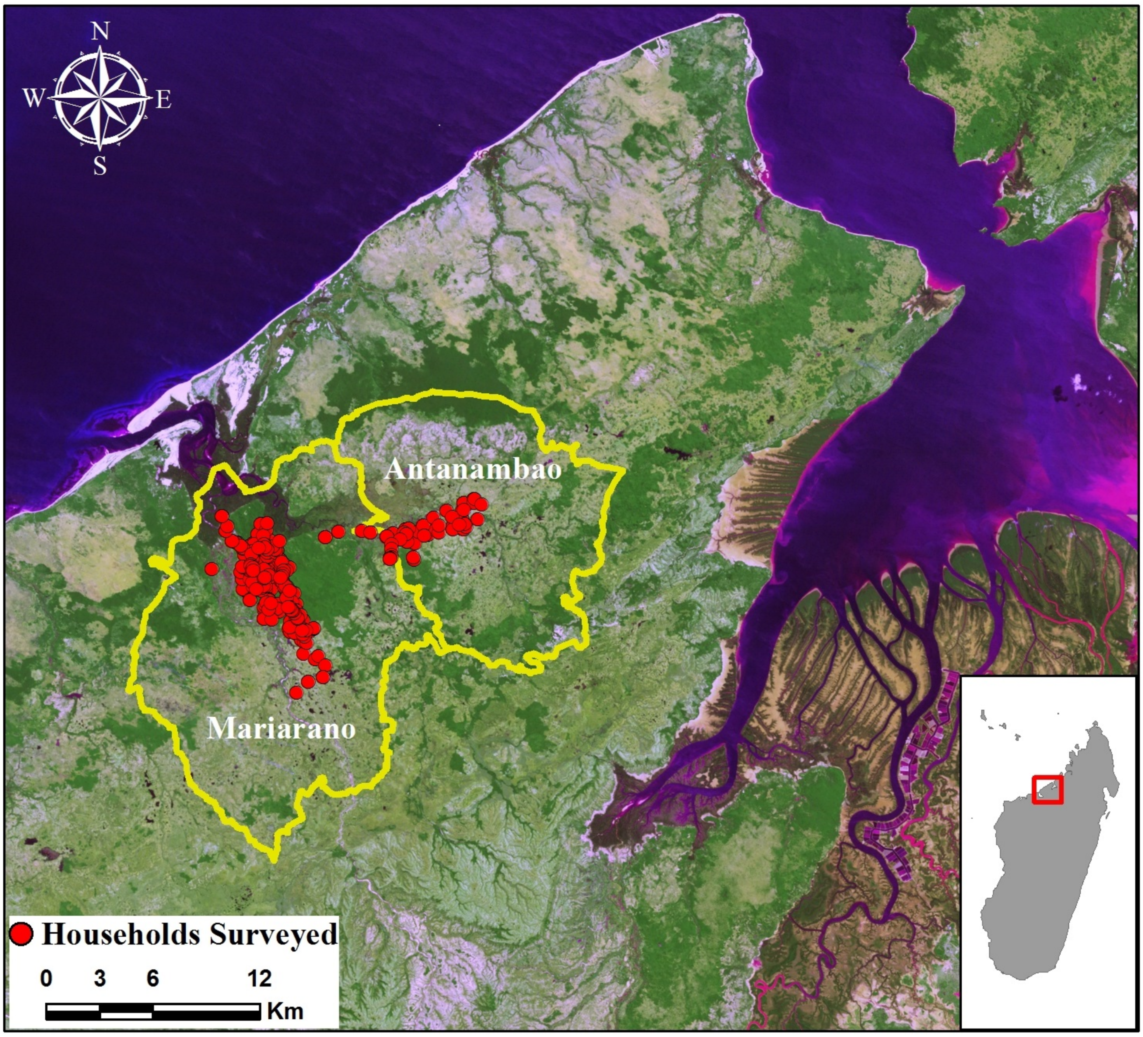

Figure 6.2 - Map showing the location of the study area within northwest Madagascar. The red dots indicate various sites at which households were surveyed, the bold boundaries encompass the *fokontany* of Antanambao and Mariarano, within the boundary of Mariarano commune. Source: Landsat-TM 5, Year: 2009

6.3 Methods

6.3.1 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.

6.3.2 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[11] supported *Programme Germano-Malagache pour l'Environnment* (PGM-E) project. Key informant interviewees included officers of the *fokontany* administrative council, and senior officers of 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

[11] GIZ - Deutsche Gesellschaft für Internationale Zusammenarbeit

scales (de Chazal et al. 2008), 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, the electoral list obtained from the *fokontany* chief provided the sampling frame. 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 70 in the two *fokontany*. Chapter 5 of this thesis presented the detailed sample selection process and the justification of setting a 26-70 years age limit for the sample (Chapter 5, page 106). Additionally, focus group discussions provided contextual and historical information based on local knowledge of the different uses of forest resources and threats to forests over time. These discussions also provided an insight into the perception of regeneration success in Mariarano after community forest management was enforced, and challenges of collective action to manage forests in Antanambao *fokontany.*

To identify prevalence of ecosystem service use, hereafter referred to as ES use*,* respondents were asked 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, two categorical questions were asked 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), respondents were asked 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, in this study analysis of participation in forest management groups is restricted to the site where these currently exist, the Mariarano *fokontany*.

6.3.3 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, a composite score from a series of Likert statements was derived (Table 6.1). 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). In this study this composite score is referred to 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).

Table 6.1 - 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	Forest 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

To assess whether people valued the role of forests membership in the forest management group was used as the dependent variable in a logistic regression. This use of membership in the local forest management group as a proxy for taking action is justified 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.

6.4 Results

6.4.1 Household characteristics

Households in this 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.

6.4.2 Forest ecosystem services, including hazard mitigation services, and livelihood benefits

This section presents 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 6.2 presents the proportions of respondents in the two sites that are dependent upon these services.

Table 6.2 - 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 group 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 92.1 % and 93.0 % of the respondents in Mariarano and Antanambao respectively extract fuelwood, timber and plants like raphia or satrana from the forest and surrounding mosaic, averaging across the three forest plant uses (shown under raw materials in Table 6.2), compared to 56.9 % in Mariarano and 63.0 % in Antanambao, respectively of the respondents who engage in honey production, catching fish, harvesting tenrecs, a small insectivorous mammal, or collecting wild vegetables, averaging across the four food items (average of values for food items in Table 6.2). 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 (32.2 % in Mariarano and 19.6 % in Antanambao) (Table 6.2). Amongst the raw materials used, polewood is used by 95.3 % of all the respondents (combining the two *fokontany*), 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, as compared to Antanambao where there is no such rule in place (Chi Square = 4.5 and p = 0.034).

While 76.7 % of all respondents (both *fokontany* combined) 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. C 6.1). 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 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 6.3). 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)[12].

All of the respondents who hunt tenrecs (34.5 % of total respondents), and collect wild vegetables and fruits (75.5 % of total respondents) 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 6.3) 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 C 6.1). 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. 6.3).

[12]J.E.R, Mr. Jean Eric Rajaobelinirina, Technical Advisor, Programme d'Appui à la Gestion de l'Environnement (PAGE/GIZ) – Antenne Boeny, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH; personal communication, March 30, 2016.

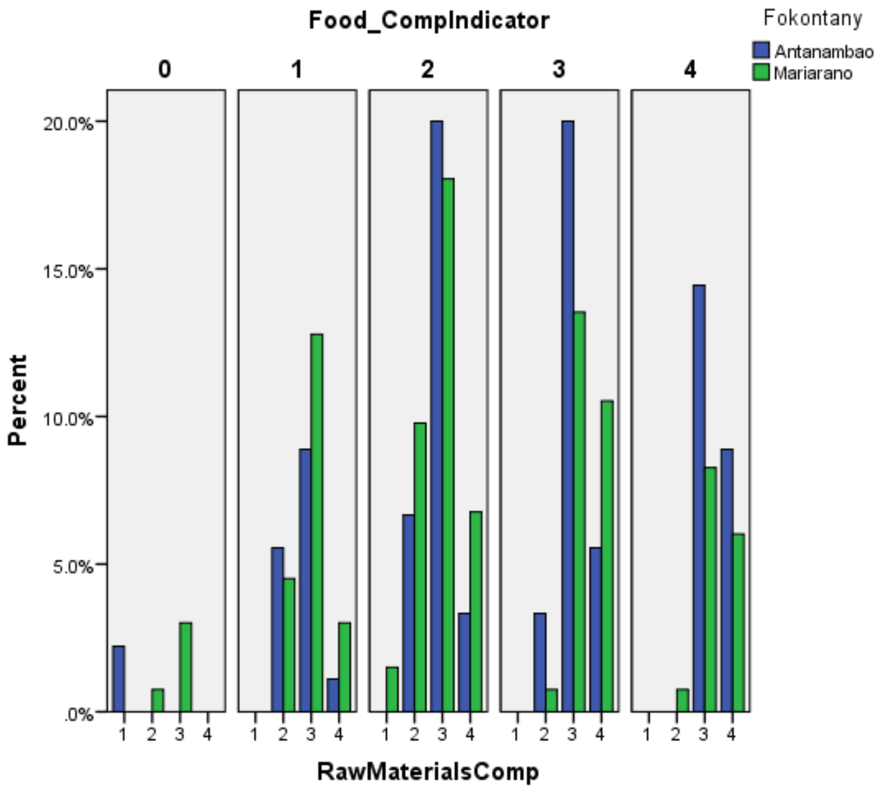

Figure 6.3 - This figure shows the level of dependence upon the four different raw materials (Raw Materials composite Indicator: fuelwood, charcoal, polewood and raphia/fiber plants) discussed here in comparison to the food items (Food composite Indicator: honey, fish, wild vegetables/fruits and tenrecs). 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).

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. No association is found between benefits from food, raw materials or tourism income and viewing forests as important for hazard reduction. This 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 figure 6.2, 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 fibre 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 per cent 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* ($r = 0.197$, $p = 0.003$).

Table 6.3 - Socio-economic characteristics as determinants of different ecosystem service uses (N = 240)

Ecosystem services used	Socioeconomic Variables	B	S.E.	Sig.	Ex(B)	95%C.I.for EXP(B) Lower	95%C.I.for EXP(B) 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		

81.9 %, 55.2 % and 60.9 % of the households 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.

6.4.3 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?

6.4.3.1 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 6.1) 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. Education is not seen 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.

6.4.3.2 Forest – hydrological cycle linkages and engaging in exploitative forest uses

One of the hypothesis of this study was 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 this anlysis uses 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 C 6.2). Results support the assumption that a more positive understanding of the forest-water cycle linkages would result in less exploitative uses of forests.

6.4.3.3 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. 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, it is seen 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 C6.3).

6.4.3.4 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 6.4). 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 6.3). 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 6.1. In addition, this lack of a causal relationship also reflects 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 6.4).

Table 6.4 - 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	.877	.414	.034	2.403	1.068	5.408
Places that provide income benefits from tourism	1.290	.530	.015	3.634	1.287	10.260
Forests reduce floods belief	.585	.452	.195	1.795	.741	4.349
Forests reduce sedimentation/debris flow belief	-.402	.525	.444	.669	.239	1.873
Education level	.934	.381	.014	2.544	1.207	5.365
Cattle owned	.433	.169	.011	1.542	1.106	2.149

Nagelkerke R square = 0.22

6.5 Discussion

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

The results presented 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). Results show that farmers in north-western 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). This 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 providers 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 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’s value for cultural services of deciduous forests.

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

The study 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 finds 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 results in this study 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, it is seen from the study presented here 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).

Several 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: the inherent risk averse nature of poorer farmers, marginalization of segments of the community, the economic costs of membership payments, however small these fees may be within the local context; labour cost constraints (Naik 1997), 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). The individual rational utility maximization model suggests that when having to contribute to a public good, a self-interested rational individual will choose to either free ride, only contribute under threat of sanctions, or when they stand to gain private benefits (Kerr et al. 2012). Hardin (1968)’s theory of the tragedy of the commons, a pessimistic perspective on the potential for collective action to manage common pool resources, such as forests, stems from this model of individual utility maximization (Kerr et al. 2012). Yet, local institutions play an important role in incentivizing prosocial behaviour and choice on the part of an individual through the existence of social norms that encourage collective action (Ostrom 1990, Kerr et al. 2012). Risk minimization by farmers may also influence farmers’ participation in forest management groups if the expected welfare levels from the perceived benefits of participating in a group is at least as high as without participation (Barrett et al. 2012). However, risk aversion may lead some farmers to choose to not participate and instead observe the effects of participation on other farmers to resolve uncertainty of benefits associated with participation in this form of collective action to manage a common pool resource (ibid). A smallholder farm household's risk aversion level is influenced by the risk associated with agricultural production, and if this is high, the value for forest resources as part of a safety-net mechanism may be higher leading to enhanced support for local forest management (Naik 1997). Further detailed empirical work is needed to understand better how and under what socio-economic, institutional or cultural circumstances, local farmers' knowledge of hazard 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 the study presented in this chapter finds income benefits derived from forests to be significant determinants of support for forest management, this relationship is not seen between management support and heavy dependence upon the forests for raw materials, food or cultural uses. This is 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 this study's 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 forests 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 based management as shown here and 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 organizations as put forward by Ostrom et al. (1999). This chapter's 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 study 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). Results show 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, it is seen 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). The study presented here has 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 this study site, 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 participate in forest management groups (Nuggehalli and Prokopy (2009). 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.

6.6 Conclusions

This research contributes 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. It shows 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. This chapter demonstrates the importance of factors such as securing complementary income from forest based honey production and tourism, relative wealth and the education levels of household heads 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 these results, two main research areas are suggested for further investigation. 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 a significant relationship (either positive or negative) was not seen 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, 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 researchers 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.

Chapter 7: Reflections and Conclusions

7.1 Introduction

The overarching aim of this study was to contribute to understanding the role of forests in mitigating extreme weather hazards and their impacts on smallholder farmers in tropical developing countries. Forest cover loss is thought to increase flood risk and is seen as a primary driver of soil erosion and consequent siltation of irrigation channels and agricultural fields (Bruijnzeel 2004, Bakoariniaina et al. 2006, Minten and Randrianarisoa 2012). Gaps remain in what is known about the conditions, magnitude and scales under which forests can moderate hazards and impacts despite decades of research (Van Dijk et al. 2009). Much of what is known is based upon biophysical assessments using small-scale experimental plots or hydrological models. Land use decisions combine with heterogeneity in soil, vegetation and channel density to add a significant level of complexity in the interacting processes and prevent broad scale predictability of the effect of forest cover change on extreme weather, storm hazards (Lambin et al. 2003, Bruijnzeel 2004, Wisner et al. 2004, Wheater and Evans 2009, Thompson et al. 2011, Kundzewicz et al. 2013).

However, an emerging field of practice is focused on evaluating the evidence for and demonstrating the significance of natural ecosystems such as forests, mangroves and other coastal habitats for reducing human exposure to increasingly frequent storms (Sudmeier-Rieux et al. 2006, IPCC 2012) and for supporting adaptation to climate change (Renaud et al. 2016). This field draws upon the Millennium Ecosystems Assessment's framework for ecosystem services, focusing on regulating ecosystem services, which include ecosystem functions such as flood control (MA 2005). A lot more is understood and discussed about the conditions under which coastal wetlands support storm hazard mitigation (Shepard et al. 2011), less is understood about similar functions played by forests, reflecting the debate in the forest hydrology literature.

Thus, the motivation for this research endeavour stems in part from the need to expand the knowledge base on the role of forests in regulating storm hazards and impacts in order to contribute to local, national and global forest management initiatives. Expanding the empirical knowledge of the contribution of forests to hazard mitigation has scientific and practical relevance to a multi-sectoral audience of practitioners and decision-makers in agricultural risk reduction, ecologically sustainable intensification of crop production, and in sustainable forest management.

As with most inter-disciplinary research questions cutting across socio-ecological systems, this problem has its set of complexities. The methodological challenges that this research problem faces are twofold. The first concerns the myriad of biophysical, geological and socioeconomic variables that interact to determine the relationship between forests, heavy rains and flood hazards at different geographic scales. The second, related challenge is that to date experimental studies designed to establish at least the biophysical links have predominantly focused on developed countries with a few exceptions (Krishnaswamy et al. 2012). One of the reasons is that these studies tend to be expensive and at small scales (Bruijnzeel 2004) or as in the case of studies based upon hydrological models, require long records of biophysical variables such as rivers discharge data that very often does not exist in developing countries. Furthermore, a key question that remains unanswered through purely biophysical assessments is whether and how such hazard mitigation forest ecosystem services are experienced and acknowledged by forest-edge communities. This question has several important implications for land use decisions, including forest management policies, and at a wider scale through the deliberations and policy recommendations of global scientific bodies such as the Intergovernmental Science-Policy Platform for Biodiversity and Ecosystem Services (IPBES).

Thus, this thesis takes a different methodological approach to study this research problem and applies it in Madagascar - one of the most biologically diverse and economically impoverished tropical countries faced with multiple stressors. The methods used include examining trends, interactions and states of key variables that characterize the broader socio-ecological system at the national and district scale in Madagascar in order to assess trade-offs and understand current system behaviours. The second set of methods is applied in a case study setting in two *fokontany* in northwest Madagascar and includes household surveys, focus group discussions, key informant interviews and participatory mapping exercises. The combined methodological approach allows for the linking of local vulnerability and interactions through case study analysis to wider socio-ecological system's dynamics.

The questions asked at the start of this research were:

1. How can the conditions of and reciprocal interactions between key socio-ecological systems variables be characterised during the recent history of Madagascar?
2. How do extreme weather hazards and consequent crop damages experienced by smallholder farmers in dry forest landscapes influence the perception of hazard mitigation benefits of forests?
3. How do deriving forest use benefits and perceiving hazard mitigation services from forests motivate participation of smallholder farmers in community forest management groups?

This thesis makes a novel contribution by expanding the knowledge base on hazard impact mitigation as part of regulating ecosystem services derived from forests in tropical landscapes, specifically with respect to dry deciduous forests. In doing so, it examines how prior experiences of weather extremes and the nature of impacts, influence local perceptions and knowledge of forest ecosystem services; how different socio-economic and geographic factors influence these impacts; and the importance of tropical dry deciduous forests to smallholder farmers who derive a broad suite of provisioning services and value local forests for their hazard reduction benefits, specifically of reducing sedimentation, flooding and debris flow. It goes on to analyse how valuing these provisioning and hazard reduction services translates into support for forest management by farmers. Furthermore, this research situates the sub-catchment case study within an examination of the socio-ecological systems' evolution at the Mahajanga II district and national scales in Madagascar. In this chapter, the key findings of this thesis, their contribution to knowledge and their implications for future research are presented, followed by reflections on the methods used and the implications of the findings for the wider global context.

7.2 Key Findings

As discussed in Chapter 1 this thesis integrates research in the field of forest ecosystem services, forest management, extreme weather linked hazards and agricultural risk reduction. It does so at two scales. Chapters 5 and 6 use data from two *fokontany* in northwest Madagascar to examine the research questions 2 and 3 through case study analysis. Chapter 4 uses multi-decadal data on social, biophysical, governance and economic indicators for Mahajanga II district and at the national scale to assess the overarching socio-ecological system's dynamics and provide an appropriate context to the case study analysis. The next section describes the key findings from these three results chapters, which respond to each of the questions guiding this research.

7.2.1 Trade-offs and system evolution patterns indicate a poverty trap

Chapter 4 addressed the question of how the connectivity between key co-evolutionary systems' variables including crop production and forest cover, can be characterised during the recent history of Madagascar at the national and district scales in an exploratory analysis. First, results of the multi-decadal trends' analyses indicated that at the national scale the system is characterized by contrasting trajectories of rising agricultural production (albeit with stagnating yields) and population, decreasing forest cover, slow and highly variable economic growth together with a high level of dependence on foreign donor assistance. Agricultural production and yield, which during the 1960s and 70s appeared to be an engine of economic growth, have not kept pace with the food demands of a growing population. Accompanying these were significant stressors in terms of repeated cyclone related damages and affected population, a declining performance on key governance indicators, including those of corruption and accountability. On the one hand, cyclone impacts can lead to greater foreign assistance flows to Madagascar, some in terms of food aid; on the other hand, political unrest and governance breakdown can lead to donor flight, as evidenced post 2009, thus reliance on external assistance increases the vulnerability of the nation as a whole, a conclusion supported by Waeber et al. (2016). Trade-offs between agricultural production and natural ecosystems such as forest cover, as seen here, are consistent with those seen around the world (e.g. Zhang et al. 2015) and one of the key challenges to achieving sustainability goals (MA 2005, Rodríguez et al. 2006). A broader socio-ecological systems analysis at the national scale, the research presented in this chapter responds to the need of combining various elements of political economy with ecological processes. It is thus shaped by the central tenet of combining the ecological with the social and political which is at the heart of political ecology (Blaikie and Brookfield 1987).

Second, results of the sequential principal component analysis (PCA) indicated an emerging decoupling between human wellbeing outcomes of reduced malnutrition, education attainment and income when combined with provisioning services and socioeconomic and biophysical system attributes. Declining interactions between key system parameters can indicate a more stable system in many cases Scheffer et al. (2012). Nevertheless, in the case of Madagascar, the emerging decoupling observed here indicates a limit to the capacity of rural, agrarian economies like Madagascar to achieve and sustain development outcomes in the absence of productive industries and freedom from governance failures. Instead, the declines observed in food production, environmental conditions and human development indicators suggest a system that is stagnating and caught in a poverty trap (Carter and Barrett 2006). Tourism is Madagascar's second most important source of revenue, and a rapidly growing one, which depends upon the forests that harbour the unique species of animals and plants. Declining forest cover not only means deteriorating environmental services but also undermines this source of growth and income. Thus, as in a poverty trap, the country seems to experience self-reinforcing mechanisms that prevent it from moving ahead on the development pathway (Carter and Barrett 2006).

The results presented in Chapter 4 reflect the many mechanisms through which poverty traps and biodiversity conservation are interlinked, including those of the failures of poor governance and corruption, high levels of dependence upon a limited set of natural resources, common exposure and vulnerability of both people and natural ecosystems to external shocks and the lack of informed management (Barrett et al. 2011). Bivariate plots showed slow stabilization in the inverse relationship between aggregate staple crop production and forest area, indicating the possible consequences of both deteriorating regulating ecosystem services and limited external output leading to lower yield and crop production, or that the policies of assigning protected area status to forests is preventing further expansion of agriculture, and thus production. There is some evidence from field studies that farmers in north-eastern Madagascar may be moving away from shifting cultivation to more permanent rice crops, especially around protected areas (Zaehringer et al. 2016). Assuming this process is happening elsewhere on the island, the stabilization seen here regionally could indicate a wider move away from shifting cultivation for the country as a whole. However, more detailed district level data on these variables across the country would be necessary to investigate this question. A bivariate plot of the number of people affected by each cyclone season and agricultural output does not show any discernible relationship. Yet Chapter 5 of this thesis explores this relationship through fieldwork at the local scale and finds clear evidence for negative impacts of extreme weather hazards at the household levels for smallholder farmers in northwest Madagascar.

Finally, at the district scale in Mahajanga II, while forest cover maintained a downward trajectory, staple crop production of rice, maize and cassava, and precipitation showed some variability in interacting variables. In similar studies, such system variability is construed as signs of system instability (Zhang et al. 2015). Here these results indicate an agricultural production system exposed to large inter-annual rainfall variability, forest loss, and primarily rain fed agriculture, complicated by additional stressors in the form of political crises, lack of governance reform and frequent exposure to tropical storms and cyclones. A longer time period of data stretching back to 1966 at the district scale would allow for more robust interpretation of system behaviour at this scale.

These results, albeit exploratory, contribute new knowledge to the understanding of the socio-ecological, political and economic complexity in Madagascar, providing a historical perspective within the constraints of available data. The results also demonstrate how the political ecology approach can inform and is reflected in the method of co-evolutionary socio-ecological systems analysis. They are particularly relevant to understanding the implications of a fragile reliance on low capital, low input agriculture, initially for sustained economic growth, but increasingly simply to meet food demands of its population, and its relationship to forest cover change. Chapter 4's results are globally relevant as they focus attention on the subset of countries or regions where human wellbeing is not a natural outcome of deteriorating ecosystem services, by highlighting that the environmentalist's paradox of improved human wellbeing in parallel with declining environmental conditions (Raudsepp-Hearne et al. 2010) does not always hold, contrary to overall global trends (MA 2005). From a policy perspective, the results in this chapter further support the utility of the development resilience concept, which can enable a multi-disciplinary and cohesive explanation of the interrelated dynamics between poverty, exposure to shocks and risks, and broader ecological processes (Barrett and Constas 2014) similar to the methodological approach in Chapter 4.

Chapter 4 also shows that at the national scale it is difficult to see bivariate association between cyclone damages and crop production or forest cover. Data constraints may limit these investigations but it is likely that several interacting mechanisms may be at work. Regular monitoring using remotely sensed data for crop productivity changes after intense storms is likely to shed light on this question at larger scales. Chapters 5 and 6 used a case study from north-western Madagascar to identify extreme weather impacts on crop production for vulnerable smallholder farmers and the benefits of tropical dry forests for both provisioning and regulating ecosystem services, such as flood and sedimentation hazard reduction, recognition by these communities and the implications of this recognition for forest management.

7.2.2 Perceived hazard mitigation benefits of forests and agricultural risks experienced by smallholder farmers

Chapter 5 of this thesis focused on the question of how previous experiences of extreme weather hazards influence smallholder farmers' perception of the role of forests in moderating the impact of hazards arising from climatic shock and variability. Smallholder farmers in forest edge communities are typically exposed to multiple weather hazards and use a mix of forest resources to cope with the impact of agricultural risks (Morton 2007, Harvey et al. 2014). Few studies, however, examine the relationship between farmers' experiences of extreme weather impacts and their perception of the role of forests in regulating floods and other storm related hazards.

The results of this chapter contribute new information to this research gap by quantifying prior experiences of weather extremes, the nature of impacts suffered and how these influence farmers' perceptions and knowledge of the role of forests in reducing hazards, specifically flood control and regulating sedimentation and debris flow onto farmland. Results from 240 household surveys and eight focus group discussions in two communities with contrasting forest cover trajectories were analyzed using multivariate statistical techniques, qualitative interpretation of focus group discussions and spatial representation of key results including proportion of rice crops lost and perceptions of forest regulating services.

Socio-economic and demographic data from household surveys used in Chapter 5 and 6 described a population living with a basic set of human and financial assets, utilizing rain fed rice production augmented with varying levels of forest product harvests and production of maize, cassava, green vegetable, fruits and livestock. Main agricultural production was focused on the staple food crops of rice, maize and cassava, with 59.6 % of the respondents producing all three and 10 % growing only rice. These results are similar to those of studies in other parts of Madagascar (Harvey et al. 2014, Poudyal et al. 2016) and in other regions of the world (Amekawa et al. 2010, Asfaw et al. 2013). Diversifying into fruit crops, livestock and wage labour were commonly utilized livelihood strategies, consistent with studies of smallholder communities in other tropical developing countries (Altieri et al. 2012). As indicated from other studies and shown in the main findings of this chapter, such households are typically vulnerable to a host of climate and non-climate stressors (Eakin 2005).

Second, hierarchical cluster analysis indicated that smallholder farmers regularly experience six main hazard impact types associated with extreme weather and storms. Two of these six types, the experience of gully erosion on parts of farmland and the experience of rapid flow of water, high winds and sedimentation that damages crops were significant predictors of holding a positive or negative view of the role of forests in hazard mitigation. Not only was experiencing gully erosion related to longer periods of food insufficiency for residents of the Antanambao *fokontany,* but this household characteristic is also correlated with seeking off farm income through wage labour. This finding contributes new knowledge to the literature on vulnerability and is consistent with other studies that show that household vulnerability is influenced by socioeconomic attributes in addition to physical exposure to hazard events (Mustafa 1998, Eakin and Bojorquez-Tapia 2008). The hazard impacts and crop losses experienced by subsistence, rain-fed smallholder production exposed to climate variability and extremes in this site is potentially similar in nature or intensity to that in other rural areas in Madagascar. However, in order that this insight can be generalized across the island nation, better records of, amongst others, cyclone and storm related crop damages need to be collected at the commune level. This is evident in the trajectories of change in the condition of variables such as staple crop production for the socio-ecological systems analysis conducted in Chapter 4. Agricultural production has remained primarily rain-fed and low input, with events such as major storms or lack of rains affecting production level of staple crops (Barrett et al. 2006).

Third, Chapter 5 presented a novel contribution to the literature on vulnerability and expands the understanding of mechanisms that integrate natural hazards and forest ecosystems by demonstrating that different hazard impact types lead to differences in whether floods, debris flow or sedimentation hazard reduction roles for forests are perceived by the respondents. Specifically, results showed that the experience of gully erosion, and the consequent perceived damage to staple crops and estimate of rice yield lost, were seen as significant predictors of holding a positive view of the role of forests in reduced flooding and regulating sedimentation and debris flow. In contrast, this positive view of the role of forests was significantly less likely in households who had experienced rapid flow of water, high winds and sedimentation resulting in loss of crops or farm area.

Finally, Chapter 5 contributed new knowledge on how well biophysical flood model results match socially perceived realities of hazard impacts by showing that while the rankings based on the flood hazard model have the expected relationships with physical location factors such slope, elevation and distance to forests, there is almost no relationship between having higher exposure to fluvial or pluvial floods and the actual experiences of hazards reported by the respondents. One possible explanatory factor could be that those areas in the case study catchments that are naturally more prone to floods have developed more resilient agricultural production systems over generations of adaptations. This is a question that can be examined in detail in further research.

The findings of Chapter 5 are significant for their contribution to understanding how smallholder farmers in forest edge communities perceive the hazard mitigation benefits of forests and how different types of hazard impact experiences influence these perceptions, thereby providing new insights on socio-ecological interactions at the local scale with implications for agricultural risk management and forest policy decision makers. Whether these positive perceptions lead to support for forest management is a question considered in Chapter 6. Chapter 6 examines in greater detail the benefits of forest ecosystems to smallholder farmers in the case study site, not only in terms of the perceived benefits of storm hazard mitigation but also for provisioning services.

7.2.3 Provisioning and hazard mitigation services derived from dry deciduous forests and support for community forest management

Chapter 6 answered the question of how deriving provisioning services from forests and perceiving hazard mitigation benefits of forests motivates participation of smallholder farmers in community forest management groups. Multivariate statistical analysis of the household survey data on forest ecosystem uses, perceived importance of forests for flood control or regulation of sedimentation and debris flow onto fields, and a Likert item question measuring the knowledge of the relationship between forest cover and the hydrological cycle, together with contextual information from the key informant interviews provide the results of this chapter. First, results showed that not only do farmers derive extensive livelihood benefits from seasonally dry tropical forest fragments in Madagascar, but they also perceived a positive role for forest cover in hydrological processes and hazard mitigation services including sedimentation and flood hazard control.

Second, the findings demonstrated that widespread 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. Only two out of the fourteen ecosystem services valued by the respondents in this study significantly influence participation in forest management groups. Results found that factors such as income from forest based honey production and tourism, and the education levels and relative wealth of households are important determinants of participation in forest management. These results are consistent with other studies (Nuggehalli and Prokopy 2009, Sodhi et al. 2010, Coulibaly-Lingani et al. 2011) that point to the importance of gaining tangible, monetary benefits from the forest, higher relative wealth and education as some of the factors that are more likely to lead to participation in community forest management groups. Third, Chapter 6 demonstrated that there is a positive relationship between avoiding exploitative use of forests (charcoal production) and valuing the relationship between forests and the water cycle.

Thus, the findings of this chapter contribute to the wider body of knowledge on forest ecosystem services and point to land use decisions that take these ecosystem services into account at least to a certain extent. Farmers are motivated to participate in community forest management (CFM) because of provisioning services, which has implications for how CFM is promoted and feeds into the debate around multiple use management regimes for forests. It is possible to assess if this insight can be generalizable to other areas of Madagascar and validate this finding by using data on the presence of operational CFM groups with remotely sensed satellite imagery data on forest cover change to capture improvements in forest cover under management regime over multiple years (Zaehringer et al. 2016). A question for future research is to examine these values for ecosystem services further and identify the specific mechanisms that may lead some people to support community level forest management as a means of ensuring the sustainability of these livelihood benefits and services. Many factors influence 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 uses influence local support for forest management initiatives (or not).

7.3 Reflections on methods used

This research integrated analyses across multiple disciplinary areas at multiple scales and used different methodologies to answer three overarching research questions, as presented in Chapters 4 – 6. This mixed method approach is standard in interdisciplinary studies and appropriate when just a qualitative or quantitative approach on its own is insufficient to provide multiple perspectives or a full understanding of the research problem (Creswell et al. 2011). The methodology used in this thesis differed significantly from the biophysical assessments with experimental watershed plots or hydrological models most often used to understand the relationships between forests and hazard mitigation. In fact, it can be argued that using a social research lens opened up the field of inquiry to a broader integration of vulnerable, smallholder farmers' livelihood practices, hazard experiences, forest benefits derived and knowledge of forest-hazard mitigation links and to understanding how such experiences and perspectives influence land use decisions. Additionally, historical analysis through the examination of multi-decadal data on key system parameters and the identification of phases within which the socio-ecological system is situated complements the cross-sectional data from the case study, provides insights on the complexities of the system at higher scales and helps to identify drivers such as governance performance that may not be apparent at smaller, more local scales but are influencing the system throughout. These broad sets of methods reflect the reliance on a political ecology framework throughout the research conducted for this thesis. Results show how different users and interest groups in the study site, access resources, perceive the storm hazard mitigation benefits of forests for their farms and how these stated perceptions and benefits influence forest management decisions. These results reflect the different components of political ecology – the state and the local (Blaikie and Brookfield 1987), negotiation over access to resources by different interest groups (Abel and Blaikie 1986) and the overarching wider context of environmental change and socio-economic development seen in Madagascar. Political ecology is relevant for policy making (Brown 1998), and results presented in this thesis are significant for the wider policy of community forest management in Madagascar and elsewhere.

An additional consideration for case study research is that the location specific conditions of environmental and agricultural decision making examined are usually influenced by external drivers of environmental change (Geist and Lambin 2002). The communities in a case study area are not living in isolation and their residents respond to external drivers which impact local land use change, such as, seen in this case, markets and demands for charcoal in urban centres that can fuel local charcoal production and thereby increase local deforestation (PGM-E and GOM 2013). In Madagascar itself, the various macroeconomic policies on agricultural production adopted under different national administrations have also led to forest cover decline across the island nation (Minten et al. 2006). Furthermore, national policies are often shaped by global political and economic events, such as price fluctuations for important food or cash crops (Zeller et al. 1999). In Madagascar, vanilla, a lucrative cash crop experiences inter-annual global price fluctuations and is susceptible to climate stressors, which can influence smallholder producers or farm workers to abandon the crop and move to farming rice as a means of subsistence. Thus, while the focus of this thesis was on local management efforts and land use decision making linked to agricultural risk reduction, the results are a reflection of the interaction of the global, state and local – again demonstrating the utility of examining these questions through a political ecology lens (Blaikie and Brookfield 1987).

One of the main constraints of conducting research in Madagascar is the availability of consistent, long-term secondary data on several indicators useful for Chapter 4. These include long term data on malnutrition, governance, and education (all extending to the mid to early 1990s only), data on cyclone damages to crops is also patchy and depends upon the capacity of the local agency to collect this information the aftermath of cyclone landfalls, thus this type of data for the early period of cyclone records until 2000 is not available. Instead we use data on the estimates of total number of people affected. There is paucity of data on regulating ecosystem service indicators such as soil erosion rates and water discharge volumes, which would have been particularly relevant to the topic. Water discharge data for some of river gauges established in the fifties was available by the month for a few years, however the records end in the 70s and early 80s, including for a station on one of the tributaries of the river Betsiboka, the nearest large river to Mahajanga II. Soil erosion data were available for two time periods from 1997 and 2001 from the FAO, thus this is not very useful. While a longer time period for some of the variables included in the analysis and additional variables would make the exploratory analyses reported in Chapter 4 richer, the data that is available and used here is already providing interesting and informative conclusions for the system as a whole.

Social surveys and participatory research methods to collect field data have their own set of challenges that are linked to the reliability of information provided by the respondents, recording of responses, translations questions and responses and consistency across enumerators (Bryman 2012). In addition, time constraints are a factor in this type of data collection. To minimize these potential for biases, enumerators were trained together in the questionnaire implementation, which included practicing household surveys and interview questions within the team. All the research methods used for field data collection were pilot tested prior to the main data collection to correct confusing questions or sections, estimate time taken and to gauge the different types of responses one could expect. In addition to training the enumerators, the researcher learned key Malagasy words and phrases often used in asking questions and in the responses to improve the validity of the translated data. As with much social research data, a larger sample size may tease out additional relationships currently not within a 0.05 significance level.

The case study site provided two contrasting characteristics: a declining forest cover in the *fokontany* of Antanambao with formal forest management for the remaining forests patches; and a regenerating forest cover at least in the section of Mariarano *fokontany* formally managed by the local association since 2001. While these two contrasting communities provide a useful comparison, there are limitations: i) the forests in Antanambao are spread out and used by people from other parts of the commune – thus there is not a close community with vested interest in sustainably using these forests, ii) the proximity between these two *fokontany* (3 hour minimum by foot) means that it is likely that residents in Antanambao are influenced by the presence of external projects and researchers present in Mariarano and consequently their responses are somehow biased. One way to overcome this potential for bias was to conduct focus group discussions and triangulate data collected during household surveys. Another factor in the case study selection was that Mariarano commune itself has now had over fifteen years of interactions with GIZ through various programs, mostly aimed at supporting local forest management.

However, this project is the first one to focus on ecosystem services and thus diminishing considerably the concern that responses could potentially be influenced by prior external influence. Nevertheless, this thesis brings up several avenues for future research which are mentioned briefly next.

7.3.1 Future Research Ideas

Three sets of research questions emerge from this project. These are:

1. On Community Forest Management: Despite widespread dependence upon local forests, farmers are making decisions about supporting community forest management purely from the expectation of tangible gains. What mechanisms exist to support the integration of regulating ecosystem services, such has hazard mitigation into this decision making?
2. On perceived hazard mitigation benefits of forests: What are the experiences and observations made by farmers that lead to a positive perception of the role of forests in mitigating extreme weather/storm related hazards in such tropical landscapes? Do these perceptions influence land use decisions in ways other than that explored in this thesis that might indirectly impact forests and their management?
3. On socio-ecological systems behaviour: Can additional data on biophysical variables such as river discharge volumes, soil erosion rates, forest cover change, at the large watershed

scales help detect a relationship between changes in forest cover and flood control and impact mitigation for storms of different intensity?

7.4 Conclusion

Forest blocks in mosaic landscapes as seen in this thesis are important to the lives and livelihoods of most smallholder farmers. Even now, smallholder farmers make up the majority of those involved in agricultural production. It thus behoves the research and practitioner community in rural development and environmental management to record and integrate information on the range of ecosystem services that forest-edge farm households rely upon into forest management policies and broader land use policies.

In conclusion, in answering the overarching research questions this thesis makes the following novel contributions to knowledge:

1. *Smallholder farmers living in forest edge communities in tropical landscapes recognize the importance of local forests for agricultural production, specifically perceiving a flood control, sedimentation and debris flow regulation benefit arising from local forests during periods of heavy rainfall.*
2. *The nature of hazards experienced and intensity of crop damage suffered influences the perception of these forest hazard mitigation benefits.* Thus, while experiencing gully erosion is associated with considering forests important for reduced floods, sedimentation and debris flow problems, other hazards do not have a significant impact on perception of forest benefits, and the hazard impact of rapid water flows, high winds and sedimentation instead lead to an opposing perception.
3. *Support for sustainable forest management is influenced by deriving tangible monetary benefits, a finding that while not completely surprising, is still important to highlight.* Individual valuation of hazard mitigation services derived from forests may not translate into support for forest management, instead community level decision making may be required. A deliberate process of engaging with farmers to explicitly come to a shared understanding of such hazard mitigation benefits may be required. Forest management policy in tropical rural communities thus actively needs to raise awareness of the regulating services derived from forests

as one component of a wider strategy to engage and incentivize local stakeholders in forest management.

4. *Declining human wellbeing indicators in parallel with the decline in regulating ecosystem services, frequent biophysical shocks and stagnant crop yields point to a socio-ecological system in danger of falling into a poverty trap or already in one.* Such trends and system behaviours, despite decades of policies aimed at enhancing agricultural production as a vehicle of economic growth demonstrate the need for applying a systems' lens through which to formulate and implement policies. Awareness and integration of the feedbacks between key variables and phase conditions into decision making on economic, social and ecological sustainability objectives can in turn ensure that the pursuit of the recently agreed upon Sustainable Development Goals (SDG), following on the MDGs is not in vain for some of the poorest countries in the world.

Appendix A Supplementary Information Chapter 4

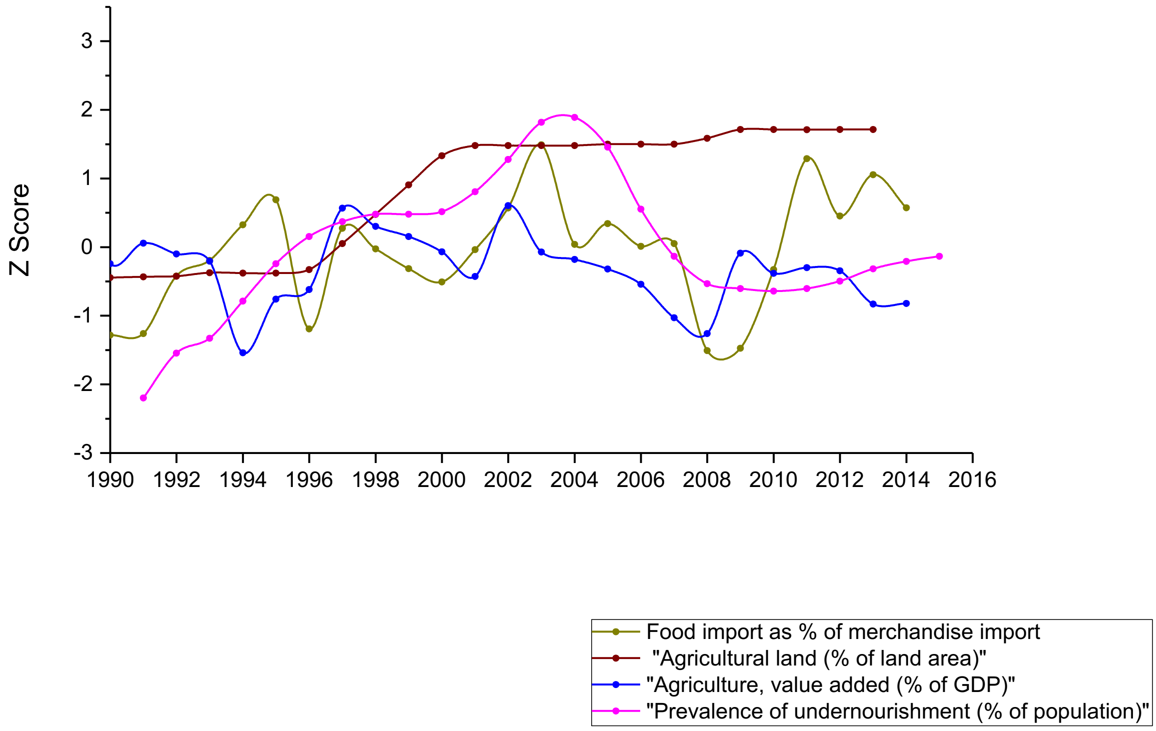

Figure A.4 1 - Food imports, agricultural land area, value added and prevalence of undernourished population.

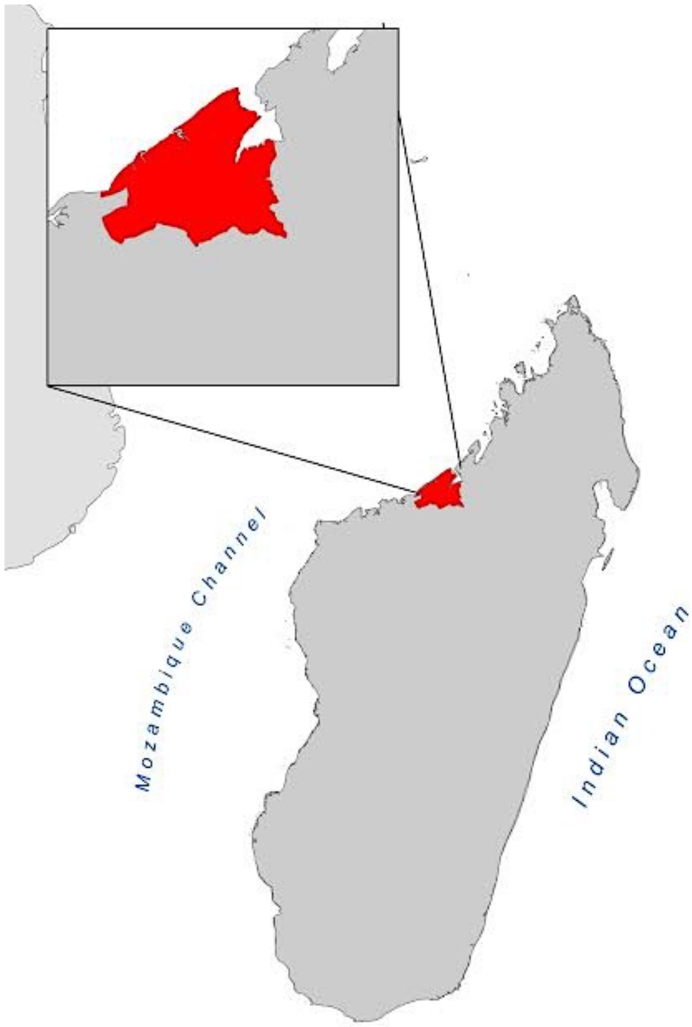

Figure A.4 2 - Madagascar, with Mahajanga II district highlighted.

Appendix B Supplementary Information Chapter 5

Table B.5 1.

	HazType1	HazType2	HazType3	HazType4	ZHazType5	HazType6
Intensity of damages (N = 233)	.443**	.147*	.008	.386**	.174**	.193**
Rice yield lost (N =217)	.411**	.143*	.080	.334**	.202**	.189**

Table B.5 2.

Variables (N= 240)	**GFM Hazard Rank**	**Hazard 1**	**Haz class2**	**Haz 3**	**Haz 4**	**haz5**	**haz 6**
Socio Economic							
	.131*						
Years spent farming							
		.168**		.154*			
Number of rice crops grown	.154*		.140*				.180**
Cattle owned					.232**		.136*
Wage labor						.185**	.276**
Number of staple crops grown			.151*	.238**			.169**
Number of other crops grown	.137*						.201**
							.146*
Household Size							
Number under 15 years							
Location Variables							
Distance to river	.205**				.145*	.239**	
Distance to forest	-.439**					-.150*	
	-.378**						
Slope							
Elevation							

Table B.5 3. - Regression results by *fokontany*: Dependent variable "believe forests and vegetation can reduce/moderate flow of sediments and debris onto fields"

		B	***S.E.***	***Sig.***	***Odds Ratio***
Mariarano					
	Erosional Gullies	0.502	0.254	0.048	1.652
	Rapid water flows, high winds, sediment laden waters	-0.823	0.274	0.003	0.439
	Intensity of damages	0.636	0.279	0.023	1.888
	Constant	1.648	0.264	0	5.194
Antanambao					
	Flooding on fields and insects infestation	0.422	0.222	0.057	1.525
	Constant	0.638	0.238	0.007	1.893

Table B.5 4. - Regression results by *fokontany*: Dependent variable "believe forests and vegetation can reduce/moderate flooding of fields"

		B	*S.E.*	*Sig.*	*Odds Ratio*
Mariarano (n =133)					
	Erosional gullies	0.44	0.212	0.038	1.553
	Rapid water flows, high winds, sediment laden waters	-0.573	0.208	0.006	0.564
	Constant	0.808	0.197	0	2.243
Antanambao (n = 82)					
	Erosional gullies	0.607	0.24	0.011	1.835
	Constant	-0.093	0.233	0.689	0.911

Appendix C Supplementary Information Chapter 6

Table C.6 1 - 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 C.6 2 - 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	.547		35.669	.000	18.420	20.594
	Charcoal producer	-.562	1.230	-.048	-.457	.649	-3.006	1.881
Mariarano	(Constant)	20.053	.437		45.927	.000	19.190	20.917
	Charcoal producer	-1.495	.779	-.163	-1.918	.057	-3.036	.046

Table C.6 3 - 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	.054	.031	.080	1.056	.993	1.122
Constant	-.700	.618	.258	.497		
Sedimentation Reduction Belief	.041	.033	.212	1.042	.977	1.112
Constant	.174	.652	.789	1.191		

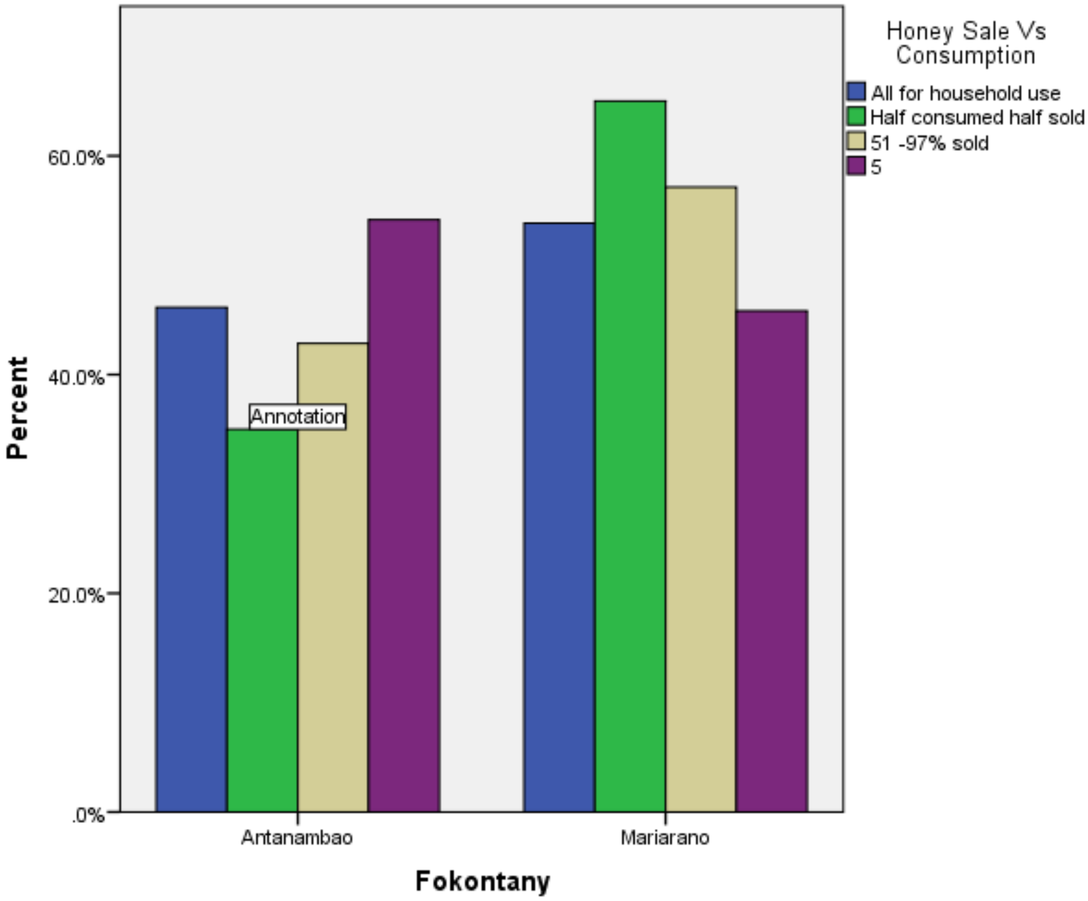

Figure C.6 1 - Proportion of households producing honey only for home consumption, for a mix of home and sale and for only selling for income.

Appendix D Household and key informant surveys

Household Survey

A: Identification and Introductory Information (fill in at the end of the interview)

Interviewer (mpanadiady) : ______________________ Date (daty): __________________

Time (ora):________________________ Day(andro): ___________________

Interviewee Code:_______
Gender of HH head (lahy na vavy): __________________

Participation consent check (fandraiana anjara amin'ny famaliana fanontaiana):
Interviewee agreed to do the interview (manaiky hanaovana fanadihadiana): Yes (Eny): _____; No(Tsia): _____
Informed Consent Form Signed (manaiky hanao sonia): _____; OR: Verbal consent recorded (NA manaiky alaina feo): ______

Interview Cross-check (momba ny fanadihadiana):

Number of questions answered: Isan’ny fanontaniana voavaly_______________
Number of questions not answered: Isan’ny fanontaniana tsy voavaly____________
Coded by : ________________________________
Date checked: _____________________________

PART 1 – Livelihoods, Land use patterns and hazard experiences
Fitadiavam-bola, fampiasàna tany ary fiatrehana fiantraikan’ny loza voajanahary

We would like to ask you about your livelihood activities: what are your main livelihoods, primary sources of income and food consumption? We are also interested in hearing about your experiences with rainfall-related problems and how these affect your food production and consumption.

I. **Income and Food Consumption Questions**

1. Which of the following do you depend upon for your income and food consumption?
Inona amin'ireto zavatra voatanisa ireto no tena fivelomanareo?

	Livelihood options **Fivelomana**	**Household Food Consumption (Yes=1, NO=0)**	**INCOME (YES=1, No=0)**	**RANK Importance for Income Source**	**Proportion of produce sold in last one year for 3 top sources**	**Estimate Income from 3 main source (Ariary)**
1	Rice production					
2	maize katsaka					
3	Cassava Mangahazo					
4	fruit crops 1. Bananas 2. Oranges 3. Lemons 4. sugarcane 5. Other:	1. Bananas 2. Oranges 3. Lemons 4. Sugarcane 5. Other:	1. Bananas 2. Oranges 3. Lemons 4. Sugarcane 5. Other:			
5	vegetables legioma 1. Potatoes 2. Sweet potatoes 3. Ovy Ala 4. Other:__________	1. Potatoes 2. Sweet potatoes 3. Ovy Ala 4. Other:________	1. Potatoes 2. Sweet potatoes 3. Ovy Ala 4. Other:__________			
6	Fishing manjono					
	Livelihood options **Fivelomana**	**Household Food Consumption (Yes=1, NO=0)**	**INCOME (YES=1, No=0)**	**RANK Importance for Income Source**	**Proportion of produce sold in last one year for 3 top sources**	**Estimate Income from 3 main source**

7	LIVESTOCK 1. Zebu 2. Chickens 3. Turkey 4. Ducks 5. Other:_______	1. Zebu:_______________ 2. Chickens: 3. Turkey: 4. Ducks: 5. Other:_______	1. Zebu 2. Chickens 3. Turkey 4. Ducks 5. Other:_______		1. Zebu:__________ 2. Chickens:______ 3. Turkey: 4. Ducks: 5. Other:_______	
8	Wage labor in commune on other's land miasa tanin'olona mpiray tanàna na fokontany					
9	Wage income from working in nearest town/city miasa tanin'olona lavitry ny tanàna					
10	Making Artisanal Products: 1. Mats 2. Baskets 3. Hats 4. Other:__________	_	1. Mats 2. Baskets 3. Hats 4. Other:__________			
11	Charcoal production famokarana saribao					
12	Camp guard, guide, transport					
13	Other strategy or food source (fomba hafa):					

Refused to reply/could not reply (99)

2. Average number of livestock owned:

Number	TYPE Of LIVESTOCK	Number:
1	Zebu owned by household	i. 1-5 ii. 6-10 iii. 11-20 iv. 21-30 v. >30
2	Chickens:	
3	Turkey	
4	Ducks	
5	OTHER	

3. How many other fields do you have for other types of crops? ________
4. How many rice fields do you use for your cultivation normally (usually)? ________
5. How many harvests of rice do you get from one field in one year?
   i. Rice field A: i) Crop Asara, ii) Crop Jeby, iii) Crop Ahitrahitra
   ii. Rice field B: i) Crop Asara, ii) Crop Jeby, iii) Crop Ahitrahitra
   iii. Ricefield C: i) Crop Asara, ii) Crop Jeby, iii) Crop Ahitrahitra

5b. Do you own all your ricefields or do you rent any?

6. Do you cultivate all these rice fields every year? If not, please explain reason. **Voavolinao isan-taona ve ireo tany rehetra ireo**? Raha tsia ?nahoana:
   1. **Yes**
   0. No

If no, Reason (antony): ____
____

7. Agricultural yield for rice:

	Ricefield A	Ricefield B	Ricefied C	Ricefield A	Ricefield B	Ricefied C
	2014			2015		
Rice ASARA (1/0)						
Rice Asara Seeds Used (Unit)						
Rice Asara Yield (UNIT)						
Rice JEBY (1/0)						
Jeby seeds used						
Jeby yield						
Rice AHITRAHITRA (1/0)						
Ahitrahitra Seeds Used						
Ahitrahitra Yield						

8. Conversion between units of seeds and yield:
   1. Unit used for planting (a): ____
   2. Unit used for yield (b):_______;
   3. Type of Gony:______________; Full: Yes/No:________
   4. Conversion Dabas to Gony:________

9. How long have you been farming? Nanomboka oviana ianao no tena namboly?
   i) 1– 5 years
   ii) 6 -10 years 6-10 taona
   iii) 11-15 years 11-15 taona
   iv) 16 - 25 years 16-25 taona
   v) More than 25 years Mihoatra ny 25 taona

10. How does the yield for rice that you get now (these last few years) compare to what you used to get earlier (before 2000)?

____
____

11. What are the 3 most important risks to your agricultural yield?
    i)_______________ii)__________________iii)_________________

12. **Now we would like to ask you some questions on your agricultural practices. Mombamomban'ny vokatra azo:**

Number	Characteristic	Ricefield A	Ricefield B	Ricefield C	Notes
1	Location				
2	Irrigated (1/0)				
3	At a distance LESS than or equal to 500 meters from riverside? (Yes/No) (1/0)				
4	Asara (1/0)				
5	Jeby (1/0)				
6	Ahitrahitra (1/0)				
7	Use Chemical Fertilizer (Yes/NO) (1/0)				
8	Organic Manure (Yes/No) (1/0)				
9	Insecticide (Yes/No) (1/0)				
	Amount used per harvest on field:				
	Price paid per harvest				
10	Use Zebu to prepare land? Yes (1), No (0)				
	Zebu Chariot (1/0)				
	Zebu Trampling (1/0)				
	Time taken for this stage				
	Number of cows used per harvest? (number)				
	Paid anyone to borrow? 1/0				
	Price paid per harvest for zebu? ARIARY				

11	Total number of people needed to manually prepare field				
	Time taken in days for this task				
	number of people from outside of family employed to work on this task?				
	Wages paid for total number of people who helped prepare land per crop type				
12	Total number of people needed to plant field				
	Time taken to plant field for each harvest				
	number of people from outside family who were paid to plant per crop type:				
	Wages paid for total number of people hired				
13	Spent time repairing or maintaining irrigation canals? (yes/no)				
	*Number of days spent fixing before and during **asara***				
	*Number of days spent fixing before and during **jeby***				

	Number of days spent fixing before and during ***ahitrahitra***				
	PAID anyone to do this job for you? (Yes/NO)				
	How much paid per crop harvest?				
14	Total number of people needed to harvest each crop				
	Time taken by you to harvest in days or months?				
	How many people paid to help with this task?				
	What is the total wage paid for total number employed to help harvest?				
15	*Do you buy or save seeds?* *Price if buy:*				

13. Since you started farming, have you ever changed the location of areas you cultivated for crops or stopped using a specific land? Efa niova toerana ambolena ve ianareo?

i) Yes: _____
ii) No: ______

If NO, go to Ques 16

14. If yes, When was the change (year)? Oviana no niova?
____

15. What was the reason for the change?(personal reasons/physical/environmental/social factors/Political /New Forest use laws after 2002).

- ☐ Bought new land
- ☐ Land no longer producing enough crop yield
- ☐ Inherited new land
- ☐ Sand and mud/sediment damage to land
- ☐ Land has floods to frequently
- ☐ No longer sufficient rain for rain-fed rice
- ☐ Other:____
____

16. A. In the last six months since December 2014, have you and your family received help from neighbours, relatives or friends in the fokontany for any of the following:

i. Prepare, plant, or harvest rice fields
ii. Repairing canals
iii. Selling animal or crops produced by you in the market or in town
iv. Letting you use their zebu or chariot for free
v. Help with taking care of children if you are away
vi. Help with getting medicines or medical care
vii. **Lent you cash**

17. In the last six months, have you helped friends, neighbors or relatives in any of the following:

i. Prepare, plant, or harvest rice fields
ii. Repairing canals
iii. Selling animal or crops produced by you in the market or in town
iv. Giving your zebu or chariot for free to use
v. Help with taking care of children
vi. Help with getting medicines or medical care
vii. **Lending money**

18. Do you experience a lean or “hungry” season when **the food you produce or can buy is insufficient** for your household’s consumption?

	Experience of lean season	**Yes (1); No (0)**	**How long does this period last for you (2 weeks, 1 month, 6 weeks, etc).** ***Number of days or weeks when personal household food consumption is reduced because of insufficient savings or insufficient financial ability to buy:***
1	Experienced lean season this year?		
2	Experienced lean season last year?		
3	Experienced lean season for at least three out of the last five years?		

☐ 99 Refused to reply

19. During the lean season, which of the following best describe your actions (what you do). Check all that apply

	Strategy	**Yes/No**	**Notes**
1	Collect wild vegetables or fruits from the forest to meet your food needs? Yes/No		
	Type collected: i) masiba *Anything else:_*		
	Number of times collected from forest in the last hungry season		

2	Reduce the number of meals in a day or reduce the amount of food consumed		
3	Eat more of cassava and/or coconuts and/or maize that you can harvest from your land to meet food needs?		
4	Make flour from satrana, antaly:		
5	Buy food from local shopkeeper or from individual during rainy season?		
	Type bought: *Amount in ARIARY SPENT:*		
6	Prepare in advance for lean season by purchasing supplies (PPN, rice) in Mahajanga before the rainy season begins and storing in your house?		
7	Have enough extra rice so that you can sell rice to others in the village during the lean season?		
8	*Have other food crops that you can sell to others in the village?*		
9	Exchange something you produced for your needs?		
10	Other:		

Hazard Experiences: In this section, we would like to ask you about your experiences rainfall linked hazards particularly to your agricultural production.

20. In the last fifteen years (or since you started farming, if less than 15 years), have you experienced any of the following in your daily life during the rainy season

Number	**TYPE OF Hazard Experience**	**Year/Name**	**Notes**
1	Rainy season that can be called "very strong" compared to normal years. (Yes/No)		
2	Changes in timing of the start of the first rainfall. (Yes/NO)		
3	Changes in distribution of the amount of rainfall during the normal period of the rainy season. (Yes/No)		
4	Less than normal rains (Yes/No)		
5	Cyclones (Yes/No)		
6	Droughts (Yes/No)		
7	Never to all (0)		

☐ 99 Refused to reply/Cannot say

21. Did you receive a warning in advance of the heavy rains, storm, cyclone or other event? Yes/No: 1/0:___________________________

22. How do these events affect your lives? Mark all that apply.

☐ 1. Fields inundated with water long enough to damage crops.
☐ 2. Erosional gullies that reduce the cropland (area available for farming).
☐ 3. Siltation of farmland for a short time (can still use it for rice in the next season).
☐ 4. Siltation of part of the rice-field and cannot use it for at least one year
☐ 5. Long term/permanent loss of fields to siltation – cannot use the land any more.
☐ 6. Water bringing a lot of sediment load that can damage crops.

☐ 7. Wind damage to crops.
☐ 8. Rapid/fast flowing water that damages crops or sweeps away soil.
☐ 9. Insect brought by heavy rains which then damaged crops
☐ 10. Access to hospital and secondary school in village of Mariarano blocked.
☐ 11. House damaged.
☐ 11. House destroyed – had to rebuild.
☐ 12. Increased sickness in family & exposure to malaria

NOTES:____

22b. What causes the flooding --- i) a lot of rains/heavy rainfall, ii) the river overflowing, or iii) a combination of both?______
22c. How high does the water level get and how long does it stay flooded?_______________

Now we would like to ask you to try to estimate how many of your fields were affected and what was the loss you suffered for your rice harvest:

23. For the most recent heavy rainfall event (2015) OR in the last 10 years (OR AS NOTED ABOVE), did you experience the following on any of your fields:
☐ A reduction of **rice yield**.
☐ A reduction of other food crops grown
☐ Other losses (for example livestock):
☐ No impact
☐ 99 Refused to reply
☐ 88 Not applicable

IF NO IMPACT, Go To Ques. 28

24. If yes, can you provide an estimate for how much of your rice harvest you lost per field that was impacted?
Compare to last year/last normal crop season:_________________________

25. What caused the reduction? ____

26. How did you respond to these impacts? (*For example, did you replant your rice fields, delay the planting, change the location where you farm?)*

____,

____

27. Were all your rice fields affected or only some? Which ones and where are these located:______________________________________

28. In the past 1 year how often on your own or together with others in the fokontany to carry out activities to respond to the impacts of heavy rains causing siltation, sedimentation, erosion or flooding that affect farms, irrigation canals, roads?

i) On your own?; ii) together with others in fokontany or village (sector)?

- ☐ 0 Never
- ☐ 1 one time
- ☐ 2 Two times
- ☐ More than two times
- ☐ More than 10 times
- ☐ 99 Refused to reply

29. Type of activity:____

Environmental Perceptions (statements about link between rainfall availability and forests – ranking: agree strongly, disagree etc). These questions are to help us understand your ideas about the role of forests in the water cycle; please give us the response you most agree with:

30. How much do you agree with the following statements? Please state your level of agreement from 1 (lowest) to 5 (agree very strongly):

	Statements	**1**	**2**	**3**	**4**	**5**	**6**
1	The forest cover in this region plays an important role in bringing rains	Disagree Completely	Disagree somewhat	Neutral	Agree	Agree a lot	Do not know
2	The rainy season here is generally sufficient for replenishing the water flow in the river each year	Disagree Completely	Disagree somewhat	Neutral	Agree	Agree a lot	Do not know
3	There is more stable supply of water in the river, streams and lakes because of the forest cover in this region	Disagree Completely	Disagree somewhat	Neutral	Agree	Agree a lot	Do not know
4	The regrowth of trees has reduced the amount of water in the river and the lakes in this area	Disagree Completely	Disagree somewhat	Neutral	Agree	Agree a lot	Do not know/Cannot say
5	Forest are important for providing reliable supply/availability of water for irrigating your rice fields	Disagree Completely	Disagree somewhat	Neutral	Agree	Agree a lot	Do not know
6	Forest cover in this region plays an important role in supporting your agricultural production capacity	Disagree Completely	Disagree somewhat	Neutral	Agree	Agree a lot	Do not know
7	The forest here are important for my family as a source of food and/or income when my agricultural produce is low or when I have insufficient money	Disagree Completely	Disagree somewhat	Neutral	Agree	Agree a lot	Do not know

31. Are you a member of the VOI? YES :_______; NO:_________

If yes, What is your main motivation for supporting the VOI or for becoming a member?____

32. Households ecosystem service benefits obtained from the forest and surrounding landscape

	Interview questions **Fanadihadiana**	**Yes=1, No=0**	**From Where?**	**Percent for home consumption vs percent for selling**	**Pay the VOI for collecting? Yes/NO; Amount**
1	Do you collect honey or practice beekeeping?		i. Forest: Type of forest:__ ii. Banja/open land: iii. In the farmsfields iv. Near house/village		Fee (Y/N):_____ Amt:__________ARIARY
2	Do you collect wild fruits/vegetables such as MASIBA?		i. Forest: Type of forest:__ ii. Banja/open land: iii. In the farmsfields iv. Near house/village		Fee (Y/N):_____ Amt:__________ARIARY
3	Do you catch fish or seafood? Mamintana ve ianareo?		i. From the sea ii. From lakes iii. Fields:		
4	Do you catch/hunt tenerecs in the open season?		i. Voi Forest ii. Other forests iii. OTHER:		Fee (Y/N):_____ Amt:__________ARIARY
5	Do you collect medicinal plants?		i. Forest: Type of forest:__ ii. Banja/open land: iii. In the farmsfields iv. Near house/village		
6	Do you collect firewood for the house?		i. Forest: Type of forest:__ ii. Banja/open land: iii. In the farmsfields iv. Near house/village		

7	Do you collect construction materials for your house or other needs from the forest or nature?		i. VOI forest ii. Other forests		Fee: Yes/No:_______ Amount:__________ Ariary
8	Do you collect wood for producing charcoal?		i. Forest: Type of forest:__ ii. Banja/open land: iii. In the farmsfields iv. Near house/village		Fee (Y/N):_____ Amt:__________ARIARY
9	Do you keep some areas of tree cover or forest on or near your field because it reduces the sand going into your irrigation canals and rice fields?		1. Riverside 2. Side of canals 3. Around/perimeter of ricefields 4. Other:______		NOTE Location of tree cover:_________
10	Do you think some areas of the forest or tree cover reduce the amount of sediments flowing onto your fields during the rainy season?				If Yes, note location of forest that plays this role:___________________
11	Do you think some areas of the forest or tree cover reduce the amount of water/floods coming onto your fields or houses during the rainy season?				If YES: note locations
12	Are there areas where you get water from for your household consumption? Where? ?		1.Pump 2. River 3. Irrigation Canals 4. Well 5. Other:		
13	Do you collect materials such as raphia, satrana, etc. to build mats (artisanal products), or thatch for the houses?				If yes, Location:

14	Are there sacred places for you in nature?				
15	Are there places that are important for you for religious or traditional ceremonies? Misy toerana fady na mananjiny amin'ny finoana na fombandrazanareo ve?				
16	Are there any places here that are important for you specifically because tourists come there and you benefit from the tourism by making cash income?				

Thank you for your cooperation, now I would like to ask some questions about you and your family

33. Household structure:

		Total number	**Children under 15**	**Adults 15 - 65**	**Older people over 65**
i	How many people in your household?				

34. How many cups of rice is eaten everyday in your household?_____ What else do you consume with it?____ Vary firy kapoaka no lany isan'andro ao an-trano? Inona avy matetika no atao loaka na sakafo hafa ankoatran'ny vary?________

35. Do you have a mosquito net?(Y/N) _______How many do you use for protection from mosquitoes?______

36. Were you born in the fokontany of Marirano?__Yes/NO____; Year:_______

37. If No, How long have you lived in the fokontany of Mariarano? (Please fill in) ______________years

38. What is your level of education? Tick only 1

- ☐ None
- ☐ Primary School
- ☐ Secondary School
- ☐ Lycee Tertiary School
- ☐ Professional qualification
- ☐ University
- ☐ Other (specify):____
- ☐ 99 Refused to reply

39. What is your ethnicity? ___________________________________

☐ 99 **Refused to say/ Doesn't know**

Key informant interview

Stage 1. Semi Structured Key Informant Interview Questionnaire

The purpose of this interview is to: understand the land use types, list the different types of hazards, assets that are exposed and consequent impacts on residents generally experienced and confirm list of last five major hazard events (years).

Ny tanjona tratrarina amin'ity fanadihadihana ity dia ny ahafantarana ireo fomba fampiasàna ny tany, ny olana sedrain'ireo mpampiasa tany, ireo fanànana izay sarompady ary ny olana atrehin'ny fiarahamonina, ary koa manamarina ny fisian'ireo olana goavana nisy nandritry ny 5 taona lasa izay.

A: Identification and Introductory Information (fill in at the end of the interview)

Interviewer: mpanadihady______________________ Date:daty____________________

Time: ora___________________________ Day: andro_____________________

Interviewee Code: laharan'ny fanadihadiana________________________

Introduction:

Hello and thank you for your time. I am a PhD student at the University of Southampton, UK. I am interested in the different types of land uses you have here, the livelihoods of the community and their experiences with hazards during the rainy season, and what actions are taken to reduce the negative impacts of the hazards over the short and long term. I am also interested in understanding how land use practices have changed here over time and how forests and forest management is taken into consideration by the people living here when they make land use decisions, especially in order to cope with hazards. We will be discussing your opinions based upon your knowledge and experiences, thus there are no right or wrong answers. Your responses will be treated in strictest confidence and your identity will not be used unless you give me permission to do so. I would be very grateful if you can help me with my research.

Salama! Misaotra anao amin'ny fandraisana. Mpianatra avy amin'ny fampianarana ambony Southampton any Angletera aho. Manadihady momba ny fomba rehetra azo ampiasana tany ety aho sy ny fiaimpiainana ety, ary ny olana sedrain'ny mponina mandritry ny fahavaratra. Toy izany koa ny fepetra noraisina manoloana izany. Tiako ho fantatra ihany koa ny zavatra mety niova tamin'ny fomba fampiasàna tany ety sy ny eritreritry ny olona momba ny ala rehefa misy ny loza voa-janahary. Hiresaka momba ny fomba fijerinao isika, ny zavatar fantatrao na tsapanao momba izany rehetra izany, hitadiavana vaholana, ka noho izany dia tsy misy valinteny marina na diso. Ny resak'isika kosa dia mijanona ho tsiambaratelo ka ny mombamomba anao rehetra dia tsy ho azon'nizaniza hofantarina raha tsy hoe tianao aseho ka manome alàlana ianao. Faly aho raha mba ampianao amin'ny fikaroana ataoko.

Participation consent check:

Interviewee agreed to do the interview: Yes /No

Nanaiky ny fanadihadihana

Interview Cross-check:

Number of questions answered: isan'ny fanontaniana voavaly ______________

Number of questions not answered: isan'ny fanontaniana tsy voavaly___________

Coded by: _________________________________

Date checked: ____________________________

We would like to ask a few questions about the different types of land use, land cover, livestock and agricultural production and market access. After that we would like to discuss your experience of different kinds of hazards you have faced in this community during the rainy season, how these impact livelihoods and what is done to reduce their impact.

Ny tianay ho fantatra dia ny mombamomba ny tany, fambolena sy fiompiana ary ny fahafahana mivarotra vokatra. Dia avy eo isika hiresaka momban'izay olana mety hiainanareo mandritry ny fahavaratra.

1. Can you provide a description of different land cover and uses in this region based on your observation and knowledge? Toponomy – local names for places within land area that belongs to the village.

   Afaka faritanao ve ny toetry ny tany sy ny fomba fampiasana tany samihafa aty amin'ity faritra ity, rah any fijerinao sy ny fahafantaranao azy? Inona avy ny anàran-tanàna misy ety?

2. Identify main land cover types, their use, ownership and timeline for increase or decrease

   Inona avy ireo karazana toetry ny tany hita aty? Havoana, tany lemaka, ala? Dia inona avy no fampiasàn'ny olona ireo tany ireo?

	Land Cover Types **Karazana tany**	**Land Uses (Livestock grazing, irrigated rice, hillslope, vegetables, other cereals, fallow, un-usable)** **Fampiasàna azy (fiompiana, tanimbary, karazana fambolena, tany tsy miasa)**	**Frequency of use** **Fotoana hiasàn'ny tany**	**Increase or decrease in area since 2000?** **Niena ve ny fampiasàna azy taorian'ny taona 2000?**	**Generally who owns this type of land?** **Iza matetika no manana io karazana tany io?**
1					
2					
3					
4					
5					
6					
7					
8					

Notes on ownership or other points: (fanamarihana momba ny fanànan-tany na hafa)____

____

3. Main agricultural products and measurement units. What are the main crop types grown here; list all:
Ireo karazana fambolena vokarina sy ny fomba famatràrana azy. Inona avy no karazana fambolena tena fanao ety?

No.	Type of crop Karazana fambolena	Unit of measurement (Kupa?)/quantity of seeds in something Famatràrana na habetsaky ny masomboly volena	Average yield obtained per crop harvest? Habetsaky ny vokatra isaky ny fiakàran'ny vokatra	Sold in market? (Yes/No/ At times) Amidy eny an-tsena ve? (Eny/Tsia/Indraindray)	If at times, when was the last time and when will you sell again? Raha indraindrat dia oviana ianao no nivarotra izany farany, dia raoviana ny manaraka?	Usual price obtained in market? Vidiny eny an-tsena

4. How is access to land decided in families within this commune? (See Laney 2002 paper)
Ahoana ny fomba fahazoana tany eo anivon'ny fianakaviana ety amin'ity faritra ity?

II. E*xperiences in the rainy season: Benefits and hazards*

Fahavaratra: ireo tombotsoa sy olana

5. Can you describe the rainy season – start/end period, and its benefits to you and the problem you face during this time?
Ahoana ny fotoana fahavaratra – fiantombohany/fiafaràny – ireo tombotsoa sy ireo olana iainanareo mandritry ny fahavaratra?

i) Please focus on the last rainy season (2014-2015)
Nanahoana ny fahavaratra farany teo? (2014-2015)

ii) Was this the same in 2013-2014?
Nitovy ve tamin'ny 2013 -2014?

iii) And the year before?
Ary ny taloha?

iv) How has your experience changed from the year 2002 (election/Ravolomanana) and now what you see?
Inona ny fiovana hitanareo tamin'ny 2002 (fitondràn-dRavalomanana) ka inona ny fiovàna misy ankehitriny?

v) Was there a particularly bad year that made people change the type of crops, or use different farmland or adopt some other change for many years after?
Nisy fotoana na taona iray manokana ve nisian'ny olana goavana ka tsy maintsy niovàn'ny olona ny fambolena nataony mandritry ny taona maro?

6. What are the main negative effects on your life and livelihood generation of the weather during the rainy season that you experience here? Please think about this year, and the last two rainy seasons. NOTE: personal experience required for this response;
Inona ny fiantraikan'ny toetrandrom-pahavaratra lehibe indrindra iainareo eto? Tamin'ity taona ity sy ny taona roa lasa? Ireo zavatra niainanao manokana?

Tick all that apply and mark, 1st – most important effect, 2nd – second most important effect, 3rd – third most important effect.

Mariho izay zavatra miantraika ka soraty hoe, 1ny manan-danja indrindra, 2 ny antenantenany, ary 3 nyfahatelo lehibe indrindra.

	Experiences that have negative impacts **Zavatra nitondra fiantraika ratsy**	**all apply to you** **niainanao manokana**	**all that apply to commune** **niantraika tamin'ny fiarahamonina mihitsy**	**Rank Import-ance** **Lanjan'ilay fiantraika (1/2/3)**	**Why are these most important effects?** **Inona no tena nampavesatra izany fiantraika izany?**
1	High water levels – fields inundated for short period (6 – 12 hours to 1 day) Rano miakatra, tondraka ny tanimboly mandritry ny adiny 6 ka hatramin'ny 1 andro.				
2	High water levels – fields inundated for long periods (1 day to 7 days) Rano miakatra, tondraka ny tanimboly mandritry ny 1andro ka hatramin'ny 7 andro				
3	High water levels – houses damaged and need rebuilding Niakatra be ny rano ka nila namboarina ny trano samba na rava				
4	Other buildings flooded Tondraka daholo ny trano sasany hafa				
5	High water levels – road impassable Miakatra ny rano, tsy misy làlana				
6	Siltation – fields filled with sand for a short time Tototry ny tany na fasika ny tanimboly mandritry ny fotoana fohy				
7	Siltation – fields permanently silted with sand Tototry ny tany na fasika elaela ny tanimboly				
8	Siltation – irrigation canals filled with sand Tototry ny tany na fasika ny làlan-drano				
9	"Lavakas"/gullies – Farmland or areas of farmland destroyed Nihotsaka ny tany ka nisy lavaka na loaka ny tanimboly				
10	Debris flows – farmland with high sediment load, debris from water flow Nitondra fako sy loto ny rano niakatra				
11	Erosion of rich soil layer Simba ny tany				
12	Change of the course of rivers, leading to definitive/long term abandonment of lands Niova ny fandehan'ny rano, ka tsy maintsy nafindra ny tanimboly				
13.	Livestock diseases and death Narary na maty ny biby fiompy				

14	Human diseases Narary ny olona				
15.	Locust invasion Tonga ny andiam-balàla				
16.	Not enough rain Tsy ampy ny orana				
17.	Rain during the wrong time of the season Tsy tonga ara-potoana na tonga tampoka ny orana				
18	Drought Maina ny tany				
19	Other negative experiences? Fiantraika ratsy hafa?				

NOTES: (fanamarihana)___________________

7. What is causing these events? Note:*Which are the relevant mechanisms that are mentioned by key informant?*

Need for a guide for the interviewer, to make sure he/she goes to the deep understanding of the mechanisms people perceive. The risk is otherwise to just stick to superficial answers which don't tell us much about the perceptions.

Inona no mahatonga ireo zavatra voatanisa teo ambony ireo? Fanamarihana: inona no zava-dehibe hiarovana ny voly amin'ireo fiantraika ratsy ireo? Ahoana ny fahazoanao ny fifandraisan'ny toetr'andro amin'ny toetry ny tany?(mila fantatra eto ny tena fomba fijerin'ny olona fa tsy valin-teny tsotra fotsiny)

8. When was the last time you had a rainy season during which any of these three most important effects occurred?
   Oviana ny fahavaratra niainanao ireo zavatra ireo farany?

   i. Year___________
   Taona

   ii. Was it linked to a cyclone? If yes, name of cyclone_____________
   Nisy fifandraisany tamina cyclone ve izany?

   iii. During what time of the agricultural calendar did it hit (corresponding to month of year)?___
   Nandritry ny fotoam-pambolena ohatry ny ahoana ny nitranga izany?

   iv. Can you remember similar events prior to this one? Yes/no
   Efa nisy zavatra toy izany nitranga ve talohan'io rah any fahafantaranao azy na fahenonao azy? (eny/tsia)

   v. If yes, please tell us about other similar events in the past: Lazalazao ny momba izay fotoana izany

   Name(anaran'ny cyclone)____, Year(taona)____

Name(anaran'ny cyclone)____, Year(taona)____

Name(anaran'ny cyclone)____, Year(taona)____

9. Use the agricultural calendar to identify time periods for cyclone or heavy rains that cause more damage to production, compared to the time period during which heavy rainfall will cause less damage.(during which period of the calendar are crops more sensitive to the impacts of storms and heavy rainfall?

   Mandritry ny vanim-potoana'ny fambolena ahoana no misy cyclone na oram-be? Rehefa ahoana no misy fiantraikany be? Rehefa ahoana kosa no tsy dia misy fiantraikany izany oram-be izany? Mandritry ny fotoana ahoana ny voly no tena saro-pady sy mora potiky ny orana?

II. ***Elements Exposed (potentially damaged or negatively affected by rainfall-linked hazards):*** *We would like to understand how you and/oryour community are affected by these events and ask for your opinion about how these events may be affecting you, your neighbours and relatives.*

Ireo zavatra saro-pady rehefa misy orana, indrindra fa oram-be? Tianay ho fantatra ireo fiantraikan'izany amin'ny fiainanao sy ny an'ny fiaraha-moninao, sy ny fomba fijerinareo izany rehetra izany.

10. What is generally most affected by these events?
    Inona no zavatra farany saro-pady indrindra mandritra io fotoana io?

	Assets/Capital Exposed or Impacted **Fanànana atahorana**	**How / What happens?** **Inona ny zavatra nitranga? ahoana?**
1.	Zebu omby	
2.	Small livestock – chicken, pigs, goats, fish Biby fiompy hafa – akoho, kisoa, osy, trondro	
3.	Rice production Vary vokatra	
4.	Beans and vegetables Tsaramaso sy legioma	
5.	Houses Trano	
6.	Access to market to sell products? Làlana rehefa mandeha mivarotra eny an-tsena	
7.	Access to the forests to collect fuelwood, honey, other forest products? Làlana mandeha anaty ala angaàna kitay, tantely na vokatry ny ala hafa	
8.	School building, hospitals, market place Sekoly, hopitaly, tsena	
9.	Other:____________ Hafa	

11. To what extent do the rainfall linked hazard affect a household's:
    Hatr'aiza ny fiantraika ny orambe eo amin'ny fiainana andavanandro

	No or Very little (0) Zara raha misy	Somewhat (1) Kely	Moderate (2) Eoeo	Very much (3) Tena ratsy
Food consumption Sakafo				
Health Fahasalamàna				
Education Fianarana				
Market Access Làlana ho any an-tsena				

Indicators of ranking: Famantàrana ny lanjan'ny fiantraikan'ny orana

Food Consumption

0. No or very little –
1. Somewhat –
2. Moderate –
3. Very Much -

Health

0. No or very little – generally no illness in family
   Tsy matetika misy marary ao amin'ny fianakaviana
1. Somewhat – one or two short (< 5 days) of illness
   Misy marary fa tsy mihoatra ny 05 andro
2. Moderate – working adults with multiple bouts of sickness
   Misy olon-dehibe matetika marary
3. Very much – Working adults sick enough to not be able to go to farm at crucial times
   Matetika marary ny olon-dehibe ka voatery tsy miasa

Education

0. No or very little – children can keep attending school
   Mbola afaka mianatra ny ankizy
1. Somewhat – children are unable to attend school for 2-3 days in a year due to bad weather
   Tsy afaka mianatra ny ankizy mandritry ny 2 na 3 andro
2. Moderate – school closes for a week or more, or children are unable to reach school for >3 days
   Voatery mihidy ny sekoly mandritry ny erinandro na mihoatra
3. Very much – children stop attending school (may be linked to family circumstances such as ill health leading to a need for children to work on farm) Yes, so make sure children don't attend because clearly because of the hazards, as there might be some

other causes. I might be exaggerating, but sometimes, the hazard might coincide with another decision/fact where the child was anyway expected to stop.
Tsy maintsy ajanona ny fianaran'ny ankizy satria tsy ampy ny olona miasa eny amin'ny tanimboly vokatry ny aretina nentin'ny toetrandro ratsy (fakafakaina tsar any fifandraisan'ny zavamisy sy ny toetrandro ratsy)

Market Access

0. No or very little – typically can continue to go to market
   Afaka mandeha eny an-tsena ihany
1. Somewhat –
2. Moderate –
3. Very much –

12. Do you think some families or areas within this fokontany are more or less affected by these rainy season problems? *Use aerial photograph/land cover map of commune to discuss this question. OR throughparticipatory mapping.*

Raha ny eritreritrao, mety misy fianakaviana ve, na tanàna tsy dia miaina an'izany fiantraika ratsin'ny orambe izany? Sarin-tanyiaraha-manao, ampiasaina hijerevana ny toerana misy ireo toerana ireo.

If yes, can you identify farms/households/areas on this map that are more or less affected? The result here could be 1) affected geographic areas, that might be interesting to map, or 2) individual/group of households, that they might even be able to name

Tondroy ireo toerana ireo eo amin'ny sarintany: 1)toerana voakasika, tokony jerena manokana, 2)toerana, tanàna, tokatrano fantatr'ireo adihadiana

13. If yes, what differences exist – what makes some areas or families more or less impacted by these events?
    Inona no mahatonga ireo tanàna na tokantrano ireo tsy voakasika?

Disaster Response: We would like to now understand how households coordinate response to prolonged effects of these storm events.

Tetik'ad'ny fiarahamonina amin'ny fiantraika ratsin'ny orana

14. Before the rainy season do you (or the community) make preparations for coping with any storms or lack of rain?
    Misy fepetra raisinao na raisin'ny fiarahamonina ve mialohan'ny oram-be na rivo-doza?

15. How does the community prepare for rainy season related hazards, particularly the three most important ones that you mention? (food savings, infrastructures reinforcing, "local migration", adoption of new agriculture, using improved or better seeds from neighbours, or from the market)?
    Inona no fepetra raisin'ny fiarahamonina hisorohana ireo olana goavana vokatry ny rivo-doza na oram-be? (tahirin-tsakafo, fanamafisana ny trano, fifindràna trano, fiovàna voly, fifanampiana hanatsara ny masomboly, na fividiànana masomboly hafa eny an-tsena)

16. After a storm or bad rainy season, are there activities you carry out in your field to reduce the impact of some of the negative impacts? Or move the zebu, livestock etc…
    Rehefa ratsy ny andro, misy ve ny famindràna ny vokatra na biby fiompy mba tsy hanimba azy?

17. Are there any actions you as an individual would like to take but cannot? ……..Yes/NO

    If yes, please explain what these are and why you cannot take these actions.
    Misy fepetra tianao ho raisina ve manoloana izany kanefa tsy afaka raisinao amin'ny maha-olontsotra anao?
    Raha misy dia azavao izany sy ny antony tsy ahavitànao manatanteraka azy.

18. How does the government support disaster risk management in this area? (Is there a BNGRC or Red Cross agent here ? Does someone come to the commune to collect information on damage to crops, houses, roads, etc ? After a storm or drought event, how do you find out about and record the damage that has occurred ? Who is responsable for this task ?)
    Inona ny fepetra raisin'ny fanjakana sy manampahefana aty manoloana ireo olana ireo ? ohatra hoe ny BNGRC? Misy olon'ny BNGRC na Coix rouge ve aty ? misy olona tonga mitsidika sy mitatitra eny amin'ny manampahefana ve aty momba ny fahasimbàn'ny voly, trano, làlana sns … rehefa avy nisy rivo-doza na maintany ? ahaona ny fomba fanaovana tatitra momban izany fahasimbana izany raha ny eritreritrao ? iza no tompon'andraitra ?

19. Are these events changing over the last 20 years? Changes could be more or less often experienced, more intense storms, longer duration, flood inundation levels higher, etc.
    Nahitàna fiovana ve izany rehetra izany nandritry ny 20 taona? Fiovàna na ratsy na tsara na ara-potoana na ny ahavon'ny rano sns

20. What is causing these changes?
    Inona no nahatonga izany fiovàna izany?

21. Now we would like to discuss your experiences with forests:
    Hiresaka momban'ny fahafantaranao ny ala isika
    i) How do they affect agricultural production, access to land for farming, grazing livestock?
       Inona no ifandraisan'ny ala sy ny vokatra, ny tany fambolena na ny biby fiompy mikarenjy?

    iii) What are the forests generally used for, are there costs or benefits from having the forests here?
       Inona no tena ampiasain'ny olona ny ala sy ny vokatry ny ala?

iv) If there are particular seasons or agricultural production periods when the benefits are more from the forest?
Rehefa vanimpotoana ohatry ny ahoana no tena mitondra zavatsoa ny ala?

v) *Note gender*: Lehilahy/ Vehivavy _____________
vi) *Note Age group*: Taona _________________
vii) How long have you lived here?firy taona no nipetrahanao tety?_____________________
viii) What is your position:inona ny asanao? ___________________________________
ix) How long have you been working in this position?firy taona no nanaovanao io asa io?
x) What is your main occupation?____________________________________
xi) What level of education have your received?_________________

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