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Resilience to Change:
Understanding Social-Ecological
Dynamics in Reef-Dependent Fishing
Communities in Madagascar



THE UNIVERSITY
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Declaration

I declare that this thesis has been composed by myself and that the work has not been submitted for any other degree or professional qualification. I confirm that the work submitted is my own, except where the work has formed part of a jointly authored publication. My contributions and those of the other authors to this work have been indicated below:

Chapter 4

Cyclone impacts on coral reef communities in southwest Madagascar.

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Chapter 6

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Abstract

Coral reefs are located across the tropics, predominantly in developing countries where reef fisheries play an important role in generating income and supporting food security. These fisheries are increasingly governed in co-management arrangements, which typically involve a form of shared management authority between local resource users and a government or non-governmental partner. As coral ecosystems rapidly degrade, driven by climate change, overfishing and other anthropogenic impacts, effective co-management will be a critical pathway to secure a sustainable future for reef-dependant coastal communities. To support locally-relevant co-management strategies, a comprehensive understanding of the local social-ecological context is required – including the environmental conditions, resource dynamics and the social and cultural setting. In this context, co-management stakeholders are increasingly investigating how different types of data, including scientific monitoring, local ecological knowledge, and citizen-science data can be used to inform management decisions. However, this remains under investigated in the context of reef fisheries co-management.

This thesis addresses this gap by studying the social and ecological dynamics of traditional Vezo fishing communities and coral reef fisheries in the Velondriake Locally Managed Marine Area (LMMA) in southwest Madagascar. The research draws on data collected over two decades including citizen science reef monitoring data (2012 -2018), social surveys conducted in 11 villages in 2016 and 2021, semi-structured and key informant interviews, participatory video and climate reanalysis data. The thesis contains four research chapters structured as research articles.

The first chapter assesses the impact and recovery of the coral ecosystem following the damage caused by Cyclone Haruna in 2013. Using generalized linear model analysis, we found the damage was spatially heterogeneous throughout the study region and that the coral reef sites showed positive signs of recovery in the two years following the cyclone. However, a shift in dominant coral species from fragile to more resilient morphologies following the cyclone indicates that an increased frequency of destructive cyclones could cause a shift in the coral assemblage.

The second chapter examines the dynamics of adaptive capacity—the capacity of individuals or groups to cope with change—in the communities of Velondriake. Adaptive capacity is found to be differentiated between social groups but relatively stable over time. The findings suggest that co-management interventions, such as livelihood programmes could improve adaptive capacity. However, findings indicate that only certain adaptive capacity indicators were significantly associated with impact and response from disturbance events, and these indicators differed between the type of disturbance. These findings underscore that caution is required when using adaptive capacity indicators in the absence of locally derived evidence of actual adaptive behaviour.

The third chapter integrates local knowledge and scientific approaches to examine catch trends and climate variability and change in the Velondriake LMMA over the past generation. The study reveals a long-term decline in fin fish and octopus fisheries that aligns with socioeconomic pressures. Shifting wind patterns were identified as a key climate variable impacting fishers' livelihoods. This chapter underscores the unequal impacts of declining catches on male and female fishers and disparities in adaptation options.

The final research chapter is an investigation of how participatory video can be used as a tool to support co-management. Participatory video is found to be a means to synthesise local knowledge concerning shifting social and ecological conditions, fostering dialogue and action towards locally relevant management interventions.

Collectively, the research in this thesis underscores the climate and ecological challenges faced by reef-dependent fishing communities and their ramifications on the social-ecological system in southwest Madagascar. It reveals differentiated resilience among community members to declining marine ecosystems and elucidates potential interventions that can be undertaken within a co-management framework to bolster the resilience of reef-dependent communities in the face of shifting conditions. Moreover, it emphasises that in data-scarce regions, local ecological knowledge and participatory research can facilitate capacity building and generate evidence to inform locally relevant marine management and governance decisions.

Lay Summary

In tropical coastal regions worldwide, coral reef ecosystems serve as vital sources of food and livelihoods for millions of people. However, these ecosystems are undergoing rapid transformations due to the combined pressures of climate change and intense fishing activities. The communities dependent on these reefs are on the frontline of these changes. In response, collaborative efforts between communities, governments, and NGOs are emerging, empowering local stakeholders to take a leading role in conserving and sustainably managing their marine environments. These partnerships have shown potential not only to benefit the marine ecosystems but also have social benefits that aid communities in facing challenges posed by climate change and other pressures. Nevertheless, the connections between societies, coral reef ecosystems, and local marine management are very complex and there are gaps in our knowledge about the interdependencies between them.

My objective in this thesis is to increase our understanding of the feedback and interactions between societies, coral reefs and local management. I investigate this issue through a study centred on traditional Vezo fishing communities and coral reef ecosystems in southwest Madagascar. Vezo communities depend on the ocean for more than 80% of their protein and income and their culture is deeply connected to the sea. Currently facing the impacts of overfishing and climate change, they represent a poignant case study of the challenges encountered by reef-dependent communities. I contribute to this objective through four independent yet interconnected research chapters.

In the first research chapter, I investigate the impact of a tropical cyclone on the coral reefs in southwest Madagascar. Tropical cyclones have always caused damage to coral reefs, and consequently, coral reefs have evolved to recover from these impacts. However, climate change is causing the frequency of very strong cyclones to increase. Coupled with other threats such as temperature-induced coral bleaching, tropical cyclones present a threat to the future of reef ecosystems. The findings from my research revealed that the cyclone caused patchy damage to reefs. Some reef sites experienced nearly no damage, while at others, nearly half of the coral was destroyed. Local management cannot prevent cyclone damage to reefs.

However, I recommend that local measures such as reducing fishing pressure on very damaged sites, could support the recovery of reefs, and hence productive fisheries, following a cyclone.

In the second research chapter, I investigate the social factors that influence how societies dependent on reefs will adapt to changing conditions amidst climate change and other threats. The ability of individuals, households or communities to adapt is related to a range of interrelated social factors. For example, it may be linked to wealth, the support available from social networks or the source of a person's income or food. This chapter has three key findings. First, I demonstrate that there is variation in the potential to adapt between social groups, such as differences between men and women and across age groups. Second, I show that these social factors stay relatively stable over time, however, there is potential for activities related to natural marine resources management to increase the adaptation options for communities. Lastly, the connections between social factors and how well communities respond and recover to climate change do not always match what we might logically expect. Following these findings, I recommend that creating socially targeted measures in the framework of local marine resource management could increase its' potential to enhance effective adaptation to climate change in reef-dependent societies.

In the third research chapter, I combine fishers' knowledge of the environment and climate change with scientific approaches to increase our understanding of ecosystem trends and climate change in southwest Madagascar. Through this research, I aimed to help address a significant challenge in the sustainable management of reef ecosystems – the lack of evidence about changes in local conditions. The research creates a 50-year timeline of fish catches, showing a decline in catches that is likely attributable to increased demand from the international seafood export market. Furthermore, the chapter provides evidence for the impacts of climate change on local livelihoods. A key finding is that the impacts of climate change and a decline in catches in southwest Madagascar are not impacting men and women equally. This research illustrates how the knowledge held by local fishers can serve as valuable evidence for making informed decisions about social and ecological management interventions.

The concluding research chapter explores how researchers can directly engage with local communities in their studies to increase the impact and relevance of their research. I employed a method called participatory video, wherein a group is supported to create a short film around a specific issue. I collaborated with four communities in southwest Madagascar to produce films about the transformation of the marine ecosystem over the past generation and its impact on their lives. I found that participatory video facilitates local capacity building, collective action and the documentation of crucial information about the reef ecosystem and society. I offer practical guidance for undertaking a participatory video project, including key ethical considerations for working with local communities on collaborative projects.

Collectively, the research in this thesis improves our understanding of how the coastal communities and the coastal ecosystems are responding to climate change and other pressures in southwest Madagascar. It underscores how local marine management can serve as a framework to help communities adapt and build resilience against climate change threats. To conclude, I emphasise the necessity for future research on the global factors driving intense fishing pressure in coral reef ecosystems, as local management alone has limitations in addressing this issue. Furthermore, I highlight the importance of considering social and environmental context in designing management interventions to support adaptation and resilience in reef-dependent societies. Lastly, the work illustrates that integrating the perspectives and knowledge of fishers into research is crucial for conservation scientists aiming to support communities dependent on reefs in the face of global challenges.

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Chapter 1: Introduction



Vezo fishers going out to sea on a *laka* (traditional wooden dug-out canoe) in southwest Madagascar. Image: GCripps

1 Introduction

1.1 Problem Statement

Tropical coral reefs comprise just 0.1% of the entire ocean surface area yet provide fish resources and coastal protection for over 200 million people (Burke et al., 2011; Ferrario et al., 2014). However, the future of coral reefs and the coastal communities that rely on them remains uncertain due to their rapid degradation from direct and indirect anthropogenic impacts (Ferrario et al., 2014; Hughes et al., 2017a, 2017b). Localised stressors to coral reefs include overfishing (McClanahan et al., 2011; MacNeil et al., 2015; Sherman et al., 2023), habitat destruction and input from sediment and land-use discharge (Hernandez-Delgado, 2015). Local stressors are compounded by global climate change impacts. This includes shifts in marine species distribution to higher latitudes and deeper water due to warmer ocean temperatures (e Costa et al., 2014; Kumagai et al., 2018) and an increasing frequency of marine heatwaves causing recurrent mass coral bleaching (Hughes et al., 2017b; Gudka et al., 2018). Additional climate-related stressors on reefs include an increase in the frequency of intense tropical cyclones, resulting in coral destruction (Cheal et al., 2017), and, ocean acidification, which may lead to a decrease in reef accretion (Pandolfi et al., 2011). The cumulative effects of anthropogenic and climate stressors accelerate declines in reef productivity (Rogers et al., 2014; Darling et al., 2017; Robinson et al., 2019), thereby reducing the availability of reef resources for those that depend on them, such as many coastal fishers globally (Barange et al., 2014; Eddy et al., 2021; Cinner et al., 2022)

Most fishers living and working in the coastal tropics qualify as small-scale fishers. Small-scale fisheries employ 90% of the world's capture fisheries workforce (Kelleher et al., 2012) and contribute to nearly 50% of the global catch consumed by humans (Pauly and Zeller, 2016). However, compared to industrial fisheries where knowledge about stocks informs efforts for sustainable management, small-scale fisheries are incredibly data-poor (Worm et al., 2009). This is particularly true for multispecies coral reef fisheries which are often located in regions with limited capacity for monitoring (Worm and Branch, 2012). In reef regions, this has led to a lack of long-term fishery information preventing the estimation of sustainable yields

(Zamborain-Mason et al., 2023). Furthermore, it can result in shifting baseline syndrome (SBS), where successive generations adjust to decreasing abundance and diversity of reef ecosystems as normal (Pauly, 1995). SBS can be caused by age-related experience of what is 'normal' as well as disruption in intergenerational communication regarding past conditions. For example, in countries with a history of colonisation, colonial perspectives were often preferentially recorded over traditional methods of data preservation creating a misrepresented understanding of historical resource use and management (Shackeroff et al., 2011; Thurstan, 2022). SBS can influence people's perception of environmental change and how it is related to social-ecological dynamics (Alleway et al., 2023), potentially inhibiting effective resource management (Bunce et al., 2008; Katikiro, 2014; Jones et al., 2020).

Compilations of coral reef biomass data which are available indicate that most reef fish stocks are below reference points for sustainable production (Zamborain-Mason et al., 2023). Thus, while confronting the crises of coral reef degradation will require international action around climate change, it is also critical that reef fisheries are managed sustainably at both global and local scales. Implementing multiscale management practices is crucial for optimising the resource potential of fisheries amidst changing conditions (Cohen et al., 2019; Darling et al., 2019; Morrison et al., 2020). This proactive approach plays a vital role in sustaining the livelihoods of millions of coastal people (McClanahan et al., 2015; Loring et al., 2019).

To improve outcomes for reef fisheries and the people who depend on them, an increasing number of governments and civil society groups are engaging local resource users in collaborative management arrangements – frequently termed co-management (Cinner et al., 2012; Rocliffe et al., 2014). Co-management often supports local stewardship, based on recognized access rights, alongside diverse social and ecological objectives (Jupiter et al., 2014; Freitas et al., 2020). Facing a future of continued decline in reef productivity due to climate change and anthropogenic pressures (Hughes et al., 2017a), coupled with the direct impacts of climate on coastal communities, such as sea-level rise, flooding, and intense storms (Change, 2023), there is increased interest in how co-management strategies can

support reef-dependent communities to adapt to changing conditions (McClanahan et al., 2008; D'agata et al., 2020; Pike et al., 2022).

This emerging focus on locally-led management solutions aligns with a growing body of literature investigating how conservation interventions, such as spatial management and gear restrictions, can be strategically designed to maintain reef ecosystem functioning and therefore the ecosystem services they provide (McClanahan et al., 2011; Darling et al., 2019; Perry and Alvarez-Filip, 2019; Morrison et al., 2020; Zamborain-Mason et al., 2023). Furthermore, there is increased focus on how social interventions associated with co-management, including livelihood strategies (Allison and Ellis, 2001), initiatives aimed at enhancing gender equity (Freitas et al., 2020; Baker-Médard et al., 2023), and the cultivation of social networks can support resilience against both chronic and acute stressors from climate and other disturbances (Barnes-Mauthe et al., 2015; Salgueiro-Otero et al., 2022). In some instances, co-management arrangements have been found to have positive effects in terms of ecological (Barnes-Mauthe et al., 2015; Salgueiro-Otero et al., 2022) and social benefits (Berkes, 2009; Barnes-Mauthe et al., 2015). However, in other instances, co-management has failed to yield positive ecological outcomes (O'Garra et al., 2023) and exacerbated existing social inequalities and power dynamics (Blythe et al., 2017). To understand how co-management can support the adaptation of coastal communities, transdisciplinary research linking ecological conditions to human well-being is required (Lombard et al., 2023). Given the inherent complexity and dynamic nature of marine social-ecological systems, this will require the better integration of diverse knowledge types, including the integration of knowledge from local resource users (Norström et al., 2020; Gerlak et al., 2023; Lombard et al., 2023).

Local resource users often have a rich understanding of complex social-ecological processes and the strongest incentive to achieve positive outcomes for tropical coastal management (von der Porten et al., 2019). As such, it is increasingly recognised that societal engagement in knowledge production is vital to assimilate science into environmental decision-making (Gerlak et al., 2023). Beyond practicalities, the meaningful engagement of local stakeholders can be attributed to recognition of social justice issues concerning decolonizing scientific methodologies

to ensure that research does not accentuate power disparities (Blicharska et al., 2017; Crosman et al., 2022; de Vos, 2022). Yet, there is a notable disconnect between the global scientific process and the effective incorporation of local knowledge and capacities (Spalding et al., 2023). Consequently, there is growing interest in methodologies for knowledge “co-production” with the ambition to integrate local capacity and prioritise and build equitable opportunities in social-ecological research (de Vos, 2022; Gerlak et al., 2023). This is underscored by the fact that knowledge co-production promises to increase the usability of science for society (Meadow et al., 2015; Wall et al., 2017). In this context, it is critical for researchers who have the ambition to support effective co-management to develop protocols that build partnerships and integrate local capacity (Spalding et al., 2023). However, collaborative research is a complex process and gaps in the practical “know-how” of co-production work remain (Djenontin and Meadow, 2018).

1.2 Research Aim and Objectives

This problem statement in Section 1.1 highlights a set of complex and interrelated social-ecological challenges and knowledge gaps that inhibit effective decision-making to support resilience in reef-dependent coastal communities in the face of climate change and ecological trends (Figure 1.1).

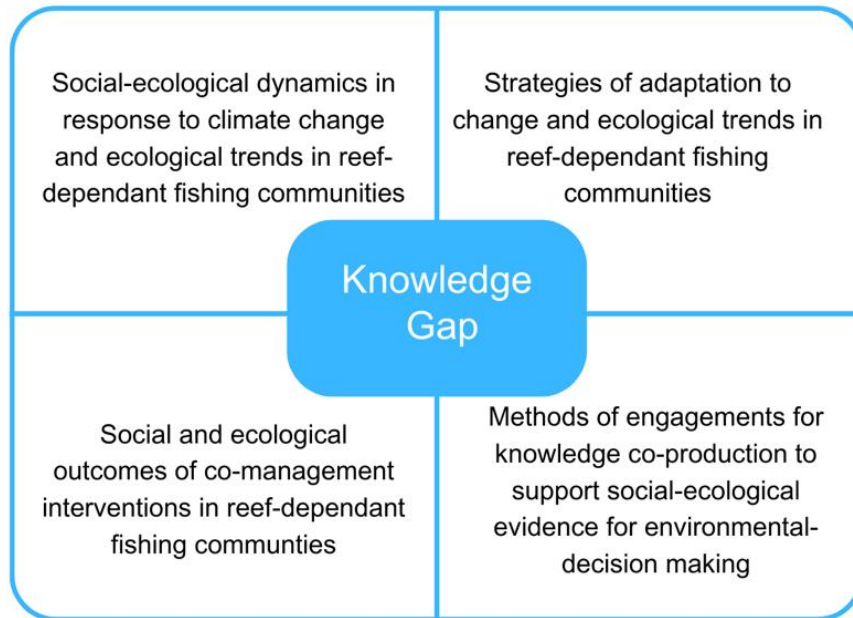


Figure 1.1 Knowledge gaps that inhibit effective decision-making to support resilience in reef-dependent coastal communities in the face of climate change and ecological trends.

In this thesis, I contribute to addressing these knowledge gaps through a transdisciplinary investigation of social-ecological dynamics in small-scale fishing communities in southwest Madagascar. In so doing, I seek to contribute to the theory and practice of effective co-management in reef-dependent communities in Madagascar and throughout the global tropics, as well as the field of marine social-ecological science more broadly. To achieve this aim, I have four overarching research objectives:

1. Reveal the ways in which social-ecological dynamics respond to climate and ecological change in small-scale fishing communities in Madagascar.
2. Understand the social dynamics of adaptive capacity and adaptation to climate and ecological change in reef-dependent small-scale fishing communities.
3. Deduce how co-management could influence social and ecological outcomes in the face of climate and ecological change.

4. Explore processes of knowledge co-production between researchers and communities to support and elicit social-ecological evidence for decision-making.

1.3 Study System Overview

A map of the study region is presented in Figure 1.2. Southwest Madagascar provides an important case study for investigating social and ecological aspects of reef fisheries co-management for several reasons. First, it is home to the Vezo, traditionally semi-nomadic fishing people who live on the west coast of Madagascar. The cultural identity of the Vezo is strongly tied to their relationship with the ocean and they have an extremely high dependence on marine resources for their food security and income (Barnes-Mauthe 2013). Second, the coral reefs of Madagascar are a biodiversity hotspot in the Western Indian Ocean (Myers et al., 2000; Brooks et al., 2006), yet like most of the world's reefs, they are confronted with large-scale disturbances and stressors, most notably coral bleaching and fishing pressure (Bigot and Quod, 2000; Gudka et al., 2018; Gilchrist et al., 2020; Gough et al., 2020). Third, Madagascar has been identified as one of the countries most vulnerable to climate change (Rakotoarison et al., 2018; Weiskopf et al., 2021) and specifically to the loss of coral reefs (Fayad, 2023), therefore local-level planning for adaptation activities is critical (Westerman et al., 2012; Weiskopf et al., 2021). Finally, Madagascar has an established network of locally managed marine areas (LMMAs) utilising co-management arrangements (often in partnership with an international NGO). Activities that occur within the framework of LMMAs have diverse objectives including sustainable fisheries, alternative livelihoods, improved food security and conservation and therefore have the potential to provide important pathways to climate resilience for local communities (Rocliffe et al., 2014; Gardner et al., 2020). Within Madagascar, the empirical work in this thesis is predominantly focused in the Velondriake Locally Managed Marine Area. Velondriake, meaning “to live with the sea” is the oldest LMMA in Madagascar covering an area of 640 km² including seagrass, coral reef and mangrove habitats. Velondriake began as an initiative to improve the sustainability of the octopus fishery but has since expanded to include aquaculture, temporary fishing closures and the designation of eight permanent no-take marine reserves (Harris, 2007, 2011; Gardner et al., 2020). The LMMA is jointly

managed by the Velondriake Association (with representatives from the 32 villages encompassed in the LMMA) and the marine conservation NGO Blue Ventures (Gough et al., 2020). Chapter 3 contains further details of relevant background and context of the study region.

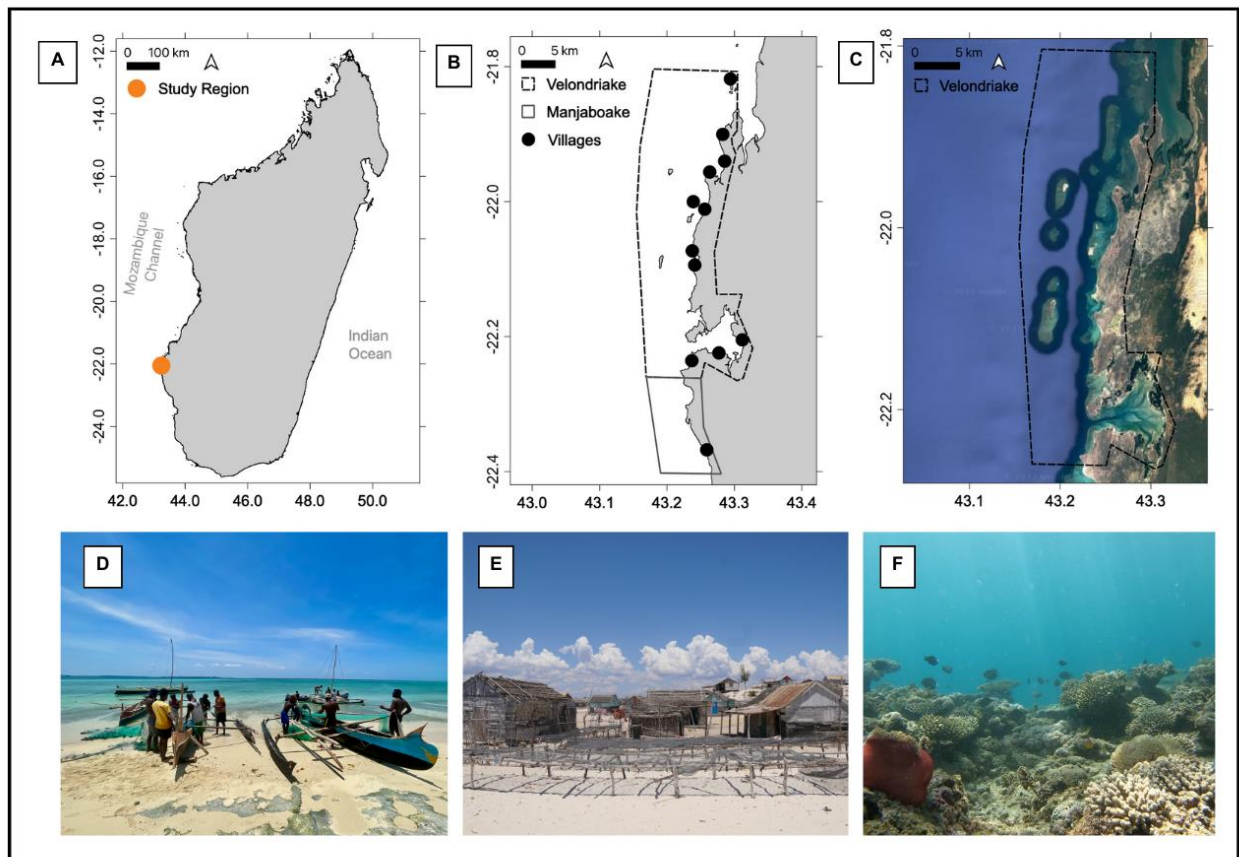


Figure 1.2. (A) Map of the study region in Madagascar. Latitude and longitude are indicated around the perimeter; (B) a map of the field sites in the study region (11 villages in Velondriake LMMA and one in Manjaboake LMMA), (C) a satellite image of Velondriake showing the barrier reef and the lagoon, (D) Vezo fishers landing their *laka* (traditional wooden dug-out canoe) on the beach after a large catch, (E) a typical Vezo village with a mix of wooden and palm leaf huts with a seaweed drying rack in the foreground, (F) a coral reef site in the Velondriake LMMA.

1.4 Thesis Outline

The research objectives in this thesis are addressed through four interdisciplinary research chapters. The research chapters were written as separate research papers for publication, two of which are already published. Because these research papers share the same study region, information regarding the case study description does reappear throughout the thesis, reframed for the context of the specific investigation.

Background for the research chapters is provided in Chapters 2 and 3 which contain a summary of the research approach and a description of the study context. The final chapter synthesises emergent themes from the thesis and proposes potential pathways for future research.

The thesis is structured as follows:

Chapter 1 Introduction. In this first chapter, I provide a background and context for the research undertaken in this thesis including a problem statement, research aims and objectives, an overview of the study system and a thesis outline.

Chapter 2 Research Approach. Here I provide a background to the theoretical approach and frameworks employed throughout the research chapters, an overview of data sources and data analysis methods and a discussion of positionality and research ethics.

Chapter 3 Study Region and Context. Here, I introduce the relevant environmental and social context of Madagascar and the study region. Understanding this context is important to draw out learnings for how this work is relevant to other reef-dependent communities and which learnings could be specific to this site.

Chapter 4 Cyclone impacts on coral reef communities in southwest Madagascar. This chapter examines the impact of Cyclone Haruna in February 2013 on coral reefs in the study region using citizen science data. I describe the implication of cyclone impacts on both coral reefs and the coastal communities dependent on them. Additionally, I provide recommendations for the use of citizen science as a tool for reef monitoring in data-poor regions.

This chapter is published in *Frontiers in Marine Science*: Carter, A.L., Gilchrist, H., Dexter, K.G., Gardner, C.J., Gough, C., Rocliffe, S., Wilson, A.M.W., 2022. Cyclone Impacts on Coral Reef Communities in Southwest Madagascar. *Frontiers in Marine Science* 639.

Chapter 5 Understanding the adaptive capacity of coastal communities in the face of diverse disturbances. Here, I investigate the dynamics of adaptive capacity in the study region through three approaches: (1) through time, (2) between different social groups, and (3) the relationship between adaptive capacity indicators and impacts and responses to chronic and acute stress events. I demonstrate variability in adaptive capacity between social groups and over time and make recommendations for applying the adaptive capacity framework in a co-management context.

This chapter is being developed into a manuscript to be submitted to the interdisciplinary journal *npj Ocean Sustainability*.

Chapter 6 Integrating fishers' knowledge to investigate social-ecological dynamics and climate change in small-scale fisheries in Madagascar. In this Chapter, I draw upon the local ecological knowledge of fishers and climate reanalysis data to explore trends in fisheries and localised climate variability and change. Additionally, I explore community perceptions and responses to shifting environmental and climate conditions. Using general additive models, fishers' recollections are used to model catch change over the past half-century and provide evidence of localised climate impacts. The results indicate gender disparities in vulnerability. Based on the results, I make suggestions for insights for co-management.

This chapter is currently under revision for publication in the journal *Ecology and Society*.

Chapter 7 Participatory video as a tool for co-management in coastal communities: a case study from Madagascar. In this chapter, I investigate the use of participatory video as a means to incorporate local knowledge and engage local communities in a co-management setting. I do this through the "Voices of the Vezo" project, for which I provided the initial framework, which was then further co-created and conducted in collaboration with local youth in four communities across the study region. Participatory video is found to be a means to synthesize local knowledge concerning shifting social and ecological conditions, fostering dialogue

and action towards locally relevant management interventions. Practical considerations for implementing participatory video projects are also outlined based on my findings.

This chapter is published in *Frontiers in Human Dynamics*: Carter, A.L., Maniry Soa, S.N., Arnull, J., Antion, P., Tudhope, A.W., Wilson, A.M.W., 2023. Participatory video as a tool for co-management in coastal communities: a case study from Madagascar. *Frontiers in Human Dynamics* 5.

Chapter 8 Discussion and Conclusion. This chapter synthesises the main findings of the thesis. I revisit the research objectives and outline the key findings and novel contributions of this work. I identify cross-cutting themes from the research chapters and propose future directions for both research and practical applications.

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Chapter 2: Research Approach



A *laka* (pirogue) on the beach in Andavadoaka. Image: ACarter.

2 Research Approach

2.1 Frameworks and Theoretical Approaches

For this research, I draw on frameworks and theoretical approaches from a variety of disciplines, which provide key conceptual intersections of enquiry across research domains. These concepts are introduced in the following section and further contextualised in each of the research chapters of the thesis. Detailed descriptions of specific research methods are provided in each research chapter,

2.1.1 Social-Ecological Systems Framework

The research in this thesis is tied together through a social-ecological systems (SES) approach. SES thinking provides an analytical lens to understand the complex interlinked dynamics of environmental and societal change (Folke and Berkes, 1998; Li et al., 2020) while putting into sharp focus humanity's dependence on nature and our escalating influence on it (Berkes et al., 2009). The SES framework is an established approach to investigate dynamics between coastal environments (e.g. coral reefs), human systems (e.g. coastal communities and marine economic sectors) and governance structures (Cinner et al., 2012, 2019; Barnes et al., 2019; Siegel et al., 2019). A benefit of the SES framework is its ability to be malleable and multipurpose, accommodating a pluralism of methods and data to suit the context (Partelow, 2018). In this research, I draw on multiple disciplines and theoretical approaches through an SES lens. These are described in detail in the relevant chapters and outlined below.

2.1.2 Vulnerability Assessments

Vulnerability in the context of social and environmental change refers to susceptibility to harm from perturbations in the social-ecological system (Adger, 2006). The vulnerability of coral reef social-ecological systems has been conceptualized through a framework which links ecological and social domains (Figure 2.1). This approach was modified from a framework promoted by the Intergovernmental Panel on Climate Change (IPCC) framework regarding the extent to which people's livelihoods are vulnerable to the impacts of climate change (IPCC, 2007). The IPCC framework divides vulnerability into three components: (1) exposure to climate impacts (2)

sensitivity to climate impacts (the extent to which livelihoods have been affected by an impact) and (3) the capacity to adapt to impacts. In the modified framework, these components have been separated into components of ecological vulnerability to exposure to climate change and social vulnerability to changes in the ecological system (Cinner et al., 2013).

Throughout this thesis, I draw on the vulnerability assessment framework to tie analysis in different disciplines together. It also provides the vocabulary for discussing how changes in the social-ecological and climate system will influence communities in the study region including discussions of climate exposure, adaptive capacity, sensitivity, and resilience.

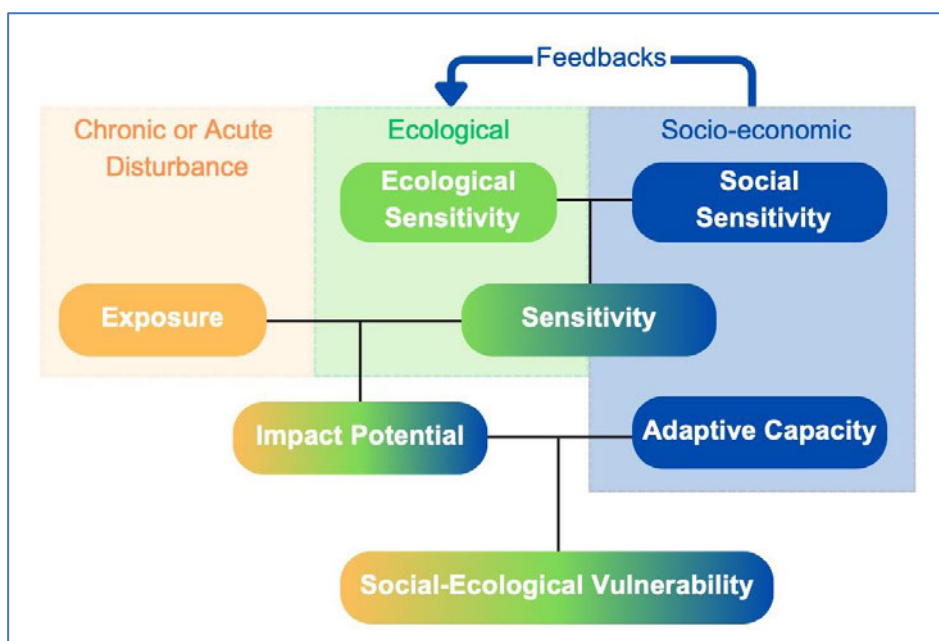


Figure 2.1. A conceptual framework for a social-ecological vulnerability assessment. Ecological sensitivity and social sensitivity together form the overall sensitivity of the social-ecological system. Socioeconomic feedbacks can influence ecological sensitivity e.g. fisheries management could decrease ecological sensitivity while overexploitation could increase ecological sensitivity. Exposure to an acute or chronic disturbance combined with sensitivity creates the impact potential for society. The impact potential and social adaptive capacity together determine social-ecological vulnerability. Adapted from Marshall et al., 2010 and Cinner et al., 2013.

2.1.3 Local Ecological Knowledge

Local ecological knowledge (LEK) is accumulated over one's lifetime from observations and interactions with ecological systems, often when utilising those ecosystems for one's livelihood (Brook and McLachlan, 2008). Traditional ecological knowledge and indigenous ecological knowledge can fall under the umbrella of LEK, but describe knowledge which transcends generations, often associated with cultural transmission and community elders (Berkström et al., 2019). The use of LEK in combination with scientific methods is an expanding field of marine social-ecological research (e.g. Carrasquilla-Henao et al., 2019; López-Angarita et al., 2021; Ullah et al., 2023). This is an acknowledgement of the fact that conventional scientific approaches and paradigms of knowledge are not enough to address large-scale environmental change (Brook and McLachlan, 2008), nor does it sufficiently integrate local stakeholder knowledge, concerns or values which are vital for sustainable management (Noble et al., 2020; Leduc et al., 2021).

Including local ecological knowledge in a social-ecological systems approach can enhance the overall understanding of ecological dynamics (especially in data-poor regions; Leduc et al., 2021; Ullah et al., 2023). It also provides a pathway to ground these changes in the experience of the communities reliant on the ecosystems for their livelihoods (Martins et al., 2018). Appropriate documentation and use of LEK requires scientists to have a collaborative relationship with the community with pathways for local input and sharing of results. (Brook and McLachlan, 2008). For this research, Blue Ventures' long-standing relationship with communities in the study region was critical in providing a pathway for the appropriate inclusion of local ecological knowledge.

2.1.4 Visual Anthropology

Visual anthropology contributes to the framing in Chapter 7. Visual anthropology focuses on the study and use of visual materials, such as photographs, films and videos, as a means of understanding local context (Collier and Collier, 1986). Visual anthropology can be integrated into a social-ecological systems framework as it offers a lens to understand the complex connections between human communities and their environments and document dynamics of interacted social and ecological

components. Involving communities in the creation of visual media supports more inclusive representation of local perspectives within the framework and allows for more nuanced comprehension of the inter-dependencies shaping human-environment interactions (Koningstein and Azadegan, 2021; Mistry et al., 2021).

2.1.5 Marine Ecology

In this thesis, marine ecology approaches are used to understand how changing tropical coastal ecosystems may impact the supply of essential goods and services to coastal communities (Cinner et al., 2016). In Chapter 4, I use data from transect and quadrat surveys to assess the impact of a tropical cyclone on coral reefs in the study region (Hill and Wilkinson, 2004). In Chapter 6, I employ approaches from fisheries science to model trends in catch weight from local ecological knowledge.

2.1.6 Climate Science

Climate science provides the evidence required to investigate the complex interactions between climate variability and change, ecosystems, and societies within the social-ecological framework (Cinner et al., 2016). I investigate historic trends in climate in southwest Madagascar and ground findings in local perspectives on climate variability and change. I use analysis methods based on climate literature to investigate decadal trends (Le Treut et al., 2006)

2.2 Primary Data Collection and Secondary Data Sources

The data used in this thesis are described in detail in the relevant chapters. Here I provide background and summary of the data collection and sources, summarised in Table 2.1.

2.2.1 Primary Data Collection

Primary data collection was significantly inhibited by international travel bans related to COVID-19, with Madagascar's international borders closed to some extent between March 2020 and March 2022 and Madagascar being on the UK government's red list of travel. I undertook two field visits to the study region: 7-weeks in 2019 (June – August) and 10-weeks in 2022 (October – December 2022). In 2019, the trip was just before the official start date of my PhD as I was acting as a

research assistant on a separate University of Edinburgh project, focused on locally-led sea cucumber aquaculture in southwest Madagascar (UOE, 2020). This experience proved to be a crucial preparatory phase for the research presented in this thesis, particularly given the subsequent travel challenges posed by COVID-19.

During the 2019 visit, I was based in the village of Tampolove, where I gained some initial familiarity with the geographical, cultural, and logistical context of the study region. By spending time in the local community and exploring the coastal ecosystems, I gained insights into the key issues that would later help shape my research questions. Understanding this local context was very beneficial for the more complex logistical planning of the second trip including feasibility of research methods, transport routes, timescales and requirements for resources and equipment. Additionally, it provided an excellent opportunity to establish relationships with local colleagues who were vital collaborators during the main research phase.

On the second field visit, I stayed in the village of Andavadoaka. During this visit, I conducted participatory video workshops in four different villages (Andavadoaka, Tampolove, Ambatomilo and Ampasilava) and undertook semi-structured interviews to investigate historic ecosystem change and fisheries trends, impacts of climate change and adaptation methods with local fishers. This work was undertaken in collaboration with the NGO Blue Ventures with further support from the Olo Be Taloha Lab (Columbia University, New York). Symphorien Nihala Maniry Soa played a central role as the lead collaborator and research assistant, supporting the organisation and execution of research activities, managing transport logistics, and aiding in the translation of interviews. Additional support came from local field assistants Valerio Sandry, Francois Lahiniriko, and Anthony Manirysoa, who assisted in the facilitation of participatory video workshops (Chapter 7) and conducted interviews with fishers (Chapter 6). George 'Bic' Manahira provided intellectual and logistical support in the field. Jess Arnall, a fellow PhD student from the School of Geosciences University of Edinburgh, with previous experience conducting research in Velondriake joined as a research assistant for four weeks.

2.2.2 Secondary Data Sources

Secondary data used in the thesis was collected by Blue Ventures as part of their activities to support the Velondriake Locally Managed Marine Area. From 2008 to 2019 Blue Ventures undertook coral monitoring in the study region as part of a marine conservation eco-volunteering programme. In this programme, participants would learn and undertake coral monitoring. This data was used in Chapter 4 of the thesis. The other data collected by Blue Ventures is a regional household socioeconomic survey. This survey was first undertaken in 2016 where approximately 10% of the adult population of villages in the Velondriake regions were surveyed. The survey was then repeated in 2021 to allow for temporal analysis. In 2021, due to COVID-19 restrictions at that time, I remotely supported the organisation of the survey including an updated sampling strategy and the addition of new questions regarding climate and COVID-19 which were employed in Chapter 5.

Other secondary data included ERA5 global atmospheric reanalysis dataset developed by the European Centre for Medium-Range Weather Forecasts (ECMWF). ERA5 provides climate and weather records from 1940 to present and is a suitable tool to investigate historic climate where climate records are lacking as it combines observations with model data (Hersbach et al., 2020). Historic cyclone tracks were retrieved from the International Best Track Archive for Climate Stewardship (Knapp et al., 2010). Sea surface temperature data for the study region was retrieved from the Integrated Global Ocean Services System (IGOSS; Reynolds and Smith, 1994).

Table 2.1. A summary of primary and secondary data sources used in this thesis

Data Type	Description	Time Period	Source	Relevant Chapter
Coral survey data	Data includes substrate cover (transect), coral morphology (transect) and coral recruitment (quadrats)	2012 - 2016	Citizen Science from Blue Ventures eco-volunteering programme and	Chapter 4
Household socio-economic surveys	Socio-economic survey	2016 and repeated in 2021	Blue Ventures	Chapter 5
Climate Reanalysis	Records of precipitation, temperature, and wind	1970 - 2021	European Centre for Medium-Range Weather Forecasts ERA5 (Hersbach et al., 2020)	Chapter 6
Observational weather data	Precipitation	1970 - 2021	Toliara weather station	Chapter 6
Cyclone Records	Historic records of cyclone occurrence, track and wind speed of Cyclone Haruna	Cyclone occurrences (1970 – 2021). Cyclone Haruna (2013)	International Best Track Archive for Climate Stewardship (Knapp et al., 2010)	Chapter 4
Sea surface temperature (SST)	Monthly SST and SST anomalies for Velondriake LMMA from blended satellite-observational product	1981 - 2021	Integrated Global Ocean Services System (IGOSS) (Reynolds and Smith, 1994)	Chapter 3
Semi-structured interviews	Questions on historic fish catches, ecosystem change,	Data collected in 2022, encompassing observations	Primary data collection during fieldwork	Chapter 5

	impacts of weather/climate and adaptation methods.	from ~1950 to 2022.		
Participatory video interviews	Questions led by participatory video participants.	Data collected 2022, encompassing historical insights	Primary data collection during fieldwork	Chapter 7

2.3 Data Analysis

This thesis employs a variety of statistical approaches, reflecting the diversity of quantitative and qualitative data used. Key modelling techniques include Generalized Linear Models (GLMs), Generalized Linear Mixed Models (GLMMs), and General Additive Models (GAMs). GLMs are suitable for a broad range of modelling tasks where the response variable may have different distributions. GLMM extends this capability by accommodating random effects which are useful in complex data structures (Bolker et al., 2009). GAMs are an extension of GLMM that allow for capturing non-linear trends, particularly useful for time-series analysis (Hastie, 2017). The selection of models was guided using the Akaike Information Criterion (AIC) to discern the best candidate among model options (Akaike, 1974). Likelihood Ratio Tests were employed to assess the performance of nested models (Bolker et al., 2009).

Thematic coding was used as the primary method for the analysis of qualitative interview data. I employed both concept-driven coding, where data is categorised in predetermined codes and open-coding which involves identifying codes from the data itself (Gibbs, 2007). Concept-driven coding allowed for targeted investigation of specific areas of interest (Ritchie et al., 2003). On the other hand, open coding offers the flexibility to capture emerging themes that might not have been anticipated initially (Corbin and Strauss, 1990).

2.4 Positionality and Ethics

Positionality plays a pivotal role in shaping a researcher's theoretical perspective, influencing the questions they ask and how they seek to answer them (Bourke, 2014). Positionality is influenced by a complex interplay of factors including social identity and context, disciplinary training and personal experience (Moon et al., 2019a). To contextualise the contents of this thesis within my positionality, I present here: a reflection on the evolution of my intellectual position through the PhD, a brief description of my social identity, a statement on research ethics and a reflection on how subject-researcher dynamics could have influenced the outcomes of the research.

2.4.1 Research Philosophy

“Research is a process, not just a product” (England, p. 82)

Before starting my PhD in 2019, I positioned myself as a natural scientist. Despite exposure to social research methods in my undergraduate (BSc Environmental Science and Business Management) and my Masters (MSc Marine Systems and Policies), my previous research focus had been underpinned, like much of the knowledge created in natural science, with an objective view, attempting to predict and explain phenomena in coral reef ecosystems through empirical research methods (Moon et al., 2021). However, after my initial field visit to Madagascar in 2019, where I began to understand the dependence of Vezo communities on healthy reef ecosystems, my perspective evolved. To understand how my research could be relevant to inform local governance and management, I was motivated to understand the phenomena of ecosystem change not only through objective approaches but against a backdrop of the worldview and lived experience of the Vezo people (i.e. interpretive theory; Crotty, 1998; Moon et al., 2019b).

However, in the subsequent two years (2020-2021) when I was unable to travel to Madagascar due to COVID-19, realising my ambition to introduce interpretive research philosophies posed a significant challenge as I was unable to conduct primary data collection. During this time, I developed Chapters 4 and 5, using data that had already been collected by the NGO Blue Ventures. The nature of this data

limited my ability to introduce interpretive approaches and therefore these chapters remain rooted in objectivism.

When I was finally able to undertake primary data collection in Madagascar in 2022, a foremost goal was to ground the research in local perspectives. In Chapter 6, I undertook an integrated methodology combining objective analysis with local ecological knowledge collected with surveys. This approach did not originate at the outset of my PhD; rather, it emerged through reflexivity of my other chapters and constantly asking the question, "How can I ensure that the perspectives of the Vezo people are represented in this research?" (Caniglia et al., 2023). My approach to Chapters 6 and 7 were also strongly influenced by my second trip to Madagascar. During this visit, I stayed in a local homestay (as opposed to staying in the local hotel), learned basic Vezo language, participated in fishing trips and attended social events and traditional ceremonies. Alongside my research activities and reading of the literature, this experience improved my understanding of local perspectives and the lived experience of social-ecological change in the region, helping to inform my research questions and the interpretation of my results.

The outcome of this intellectual development throughout my PhD. journey is an interdisciplinary thesis that integrates natural and social sciences, employing both objective and interpretive theoretical approaches. While the diversity of approaches employed is unconventional, they were deemed appropriate and necessary in the context of research to support urgently needed positive change for ocean ecosystems and the communities that rely on them. Equitable and effective ocean governance calls for a departure from traditional disciplinary boundaries and a reassessment of how we generate and share knowledge with the communities we, as conservation scientists, aim to support (de Vos, 2022; Lombard et al., 2023; Spalding et al., 2023).

2.4.2 Social Identity and Potential Bias

Underscoring my research positionality is my social identity in the context of southwest Madagascar. My research interactions would have been impacted by my identity as a white female researcher coming to do research in Madagascar through collaboration with Blue Ventures, a European organisation. My research activities

are situated within a complex landscape of historical and contemporary power dynamics of a foreign NGO operating in Madagascar. The legacies of these power dynamics trace back to Madagascar's colonisation by France, yet in a conservation-context perpetuated after independence due to the substantial power and control granted to international NGOs over local resources and knowledge systems. (Scales, 2014; see Section 3.6 for further discussion on this topic).

While undertaking my research Madagascar, I observed a spectrum of reactions to my presence from some people being reluctant to talk in front of me to others being very enthusiastic to talk due to novelty and interest. My association with Blue Ventures likely influenced some of my research interactions. This may have motivated people to provide strategic responses or to withhold information that does not align with Blue Ventures' philosophy and programmes in the region. I tried to mitigate this through the research design and clarifying my impartiality, despite my association with Blue Ventures when I explained the project to participants. Nevertheless, misperceptions and perceived power dynamics may have produced biased responses.

I recognise a key pathway of bias in this thesis is the translation from Vezo Malagasy to English. Particularly in the context of this research, the Vezo dialect has several terms which describe a state, activity and way of being in the ocean. These are difficult to translate directly, and it is likely that details went missing in the translation. I worked with local research assistants fluent in Vezo and English, however, I am aware that the subjectivity of the assistants could have influenced the translation of interviews.

2.4.3 Research Ethics

All the research contained in this thesis which involved human subjects was approved by the University of Edinburgh (individual reference numbers are stated in each chapter). All research in Madagascar was conducted in collaboration with Blue Ventures, under a Memorandum of Understanding (MOU) with the Malagasy Government. This agreement allows Blue Ventures to approve and supervise research which can contribute to knowledge to support their activities related to the Velondriake Locally Managed Marine Area. Research plans were reviewed by Blue

Ventures staff in Madagascar. Feedback on methodologies was also sought from experienced researchers based in Andavadoaka who work with the Olo Be Taloha Lab.

Before commencing activities in any village, I gained consent from the *fokotany* (the village president). Each research participant was provided with a verbal explanation of my identity, the purpose of the research and confidentiality stipulations before starting research activities. It was communicated that participants could withdraw from the activity at any time and skip questions they did not feel comfortable with without affecting compensation for their time or their relationship. For surveys and interviews, verbal consent from the participants was considered appropriate as levels of illiteracy in the region are high. Written consent was obtained in cases where the engagement in the research was more involved, such as with the participatory video participants in Chapter 7. I provided compensation to the research participants based on the activity they participated in (e.g., a 15-minute survey versus a full day of participatory video), this was based on the average wage of 7 USD per day. During longer activities I also provided refreshments. This gesture was a sign of goodwill and gratitude in return for their time.

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Chapter 3: Study Region and Context



Fishers arriving to shore at Nosy Hao after a large catch. Image: ACarter

3 Study Region and Context

This chapter introduces relevant environmental and social context of the study region and Madagascar more broadly. This is not designed to be an extensive review; however, it provides important context for the multi-disciplinary research approaches and findings of this thesis.

3.1 Southwest Madagascar Geography and Climate

Madagascar is located off the southeast coast of Africa, it is 1650km in length extending from latitude 12°S to 26°S and has a maximum width of 600 km from longitude 43°W to 51°W. A mountain ridge with an altitude of 1200 m and massifs of up to 2600 m extends the entire length of the island along the central east side which creates topographic asymmetry.

3.1.1. Overview of Climate

Madagascar's intrannual climate is affected by the monsoon of the southwestern Indian Ocean. There are two recognised seasons: hot and rainy from November to April and a cooler dry season from May to October (Jury et al., 1995; Jury, 2016). The influence of monsoon winds is strongly controlled by the topography producing a strong climatological gradient across the country. In the north of the island, rainfall in the austral summer (December – February) is above 12mm/day, in the top 1% of rainfall intensities worldwide. In contrast, the southwest is a semi-desert environment, receiving a mean of 2mm/day (Jury, 2022). Likewise, summer daytime temperatures range between 20°C to 35°C in the eastern side and north of the island but in the southwest reach up to 44°C. Sea surface temperatures in the Mozambique channel range between 25°C to 29.5°C (Jury, 2022). Madagascar has the greatest risk of cyclones in Africa; being impacted by three to four cyclones per year between November and April (Rakotoarison et al., 2018).

3.1.2. Climate Variability and Change

The Indian Ocean subtropical dipole and El Niño Southern Oscillation (ENSO) constitute primary remote drivers of interannual climate variability in Madagascar

(Zinke et al., 2004). These phenomena induce anomalous patterns of rainfall and sea surface temperatures. In the southwest, El Niño conditions in the tropical Pacific are commonly associated with reduced rainfall and elevated sea surface temperatures in the Mozambique Channel (Gudka et al., 2018).

An increase in air temperature has been observed across Madagascar (Cochrane et al., 2019; Randriamarolaza et al., 2022). Between 1950 and 2009, maximum air temperature increased at a rate of 0.23°C per decade across the island (Kameni Nematchoua et al., 2018). Precipitation trends are less spatially coherent between regions (Tadross et al., 2008; Randriamarolaza et al., 2022). However, Randriamarolaza et al. (2022) found downward trends of total precipitation at weather stations in the southwest from 1950 to 2018. Since the 1980s there have been an increased number of drought events in the south of the country (Randriamarolaza et al., 2022). Under future climate scenarios, the frequency of intense tropical cyclones in Madagascar is expected to increase (Tadross et al., 2008).

Since 1950, sea surface temperature in the Western Indian Ocean increased by 0.6°C (Raholijao et al., 2019). Sea surface temperature derived from blended observational and satellite data (IGOSS) for the study region indicates sea surface temperatures have increased by 0.4°C since 1980 (Figure 3.1).

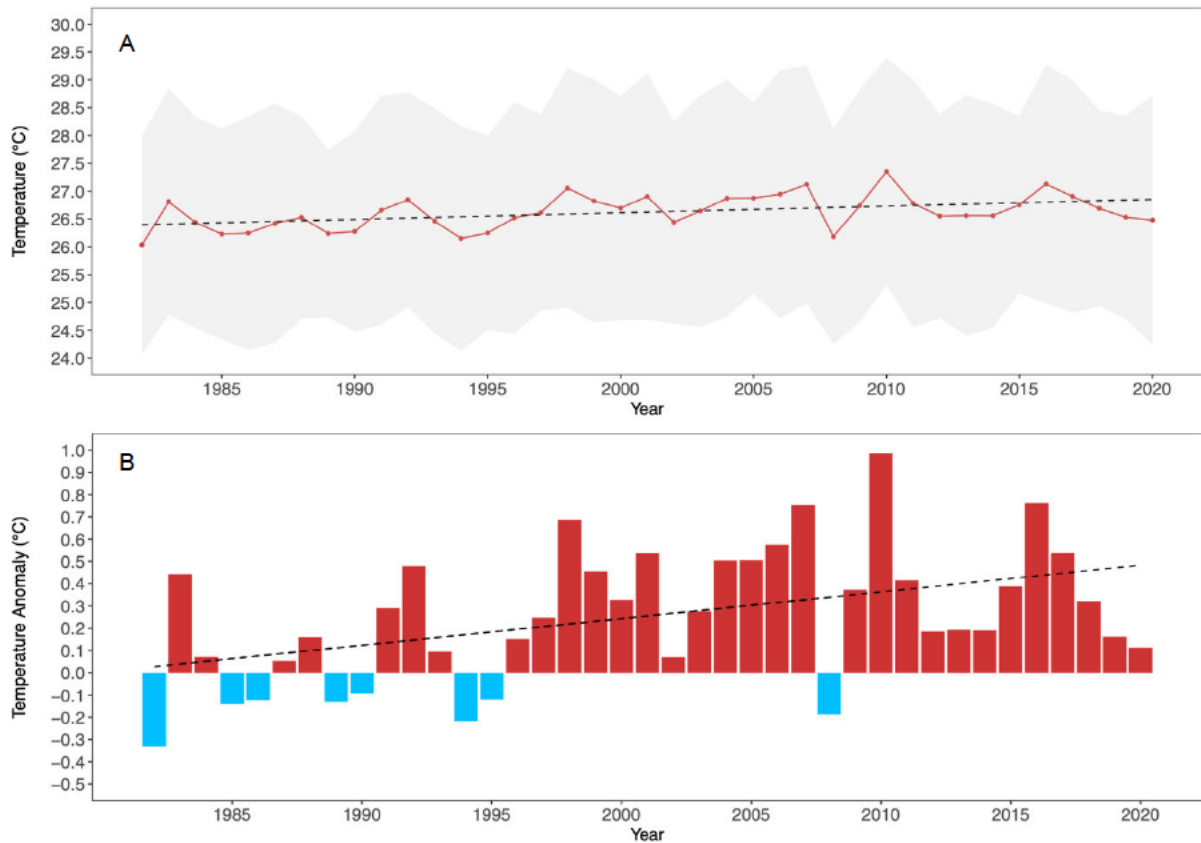


Figure 3.1. Sea surface temperature (SST) and temperature anomalies from 1981 to 2020 in the Velondriake Locally Managed Marine Area derived from monthly IGOS SST. (A) Mean annual sea surface temperatures (red line), standard deviation (grey ribbon) linear trend (dashed line); (B) Mean annual anomalies (bars) and linear trend (dashed line) relative to 1971 to 2001 climatology.

3.2 Present Socioeconomic Context

Madagascar has a population of approximately 30.5 million (IMF, 2023). The country has experienced two decades of weak economic growth, driven by governance challenges, limited human and physical capital development, and a slow pace of structural transformations. Weak economic growth combined with rapid population growth has resulted in Madagascar having one of the highest poverty rates in the world and in 2022 75% of people were living below the national poverty line (World Bank, 2024). Historically, the coastal regions of Madagascar have higher incidences of poverty (Horning, 2008; Moran et al., 2008). Population increase is happening more rapidly at the coast due to coastal migration of inland communities due to agriculture failure (Harris, 2011). The coastal economy of the southwest is heavily reliant on export production of marine resources with coastal communities reporting over 80% of income from fishing (Barnes-Mauthe et al., 2013; Tucker et al., 2015).

3.3 Small-Scale Fisheries in Madagascar

3.3.1 Madagascar Fisheries Overview

The World Bank estimated the value of the Gross Marine Product in the Western Indian Ocean to be \$20.8 billion, of which over half was attributed to Madagascar (Cripps and Gardner, 2016). Distant water fishing nations (DWFN) dominate the industrial activity within the exclusive economic zone of Madagascar. From 2012 to 2020, Taiwanese longliners (focused on tuna) were most prevalent and accounted for 39.8% of all fishing efforts. Other DWF nations constituting the bulk of fishing activity include France, Japan, China, Korea, Malaysia, and Spain (White et al., 2021). Madagascar shrimp trawlers accounted for 17.2% of fishing effort during this period, although they were first recorded in only 2018 (White et al. 2021). Questions of equity surround the permits and licenses granted by the Malagasy government to powerful DWFN. For example, from 1986 to 2010, while catch quotas for the EU increased by 30%, Madagascar's financial benefit decreased by 90% (Le Manach et al., 2013). Given the lack of transparency in fishing agreements, along with inadequate monitoring and enforcement capacity, Madagascar is highly vulnerable to illegal, unreported and unregulated (IUU) fishing. For example, Le Manach et al. (2012) found the total catches between 1950 and 2008 were twice the volume reported by the national fisheries agencies. This is in part due to the absence of much of the small-scale fisheries sector in national fishery statistics.

3.3.2 Status of small-scale fisheries in southwest Madagascar

Approximately 1.5 million people are dependent on fisheries and aquaculture in Madagascar (FAO, 2019). Most of these people live in rural coastal areas and engage in small-scale fisheries. SSF fisheries are estimated to contribute up to 65% of total fish production (Le Manach et al., 2011), however, this sector remains extremely data poor and its contribution to the national economy and food security is greatly undervalued (Gough et al., 2020). At the end of the 20th century, the SSF market shifted from a predominantly national market for dried and salted fish to catering for an international export market for octopus and large reef and pelagic species (Brenier et al., 2011). Accompanying this shift was a change from a largely subsistence and barter economy to a fisheries-dependent cash-based economy (Gardner et al., 2017). The research in this thesis is predominantly focused on two

key fisheries: coastal fin fish and intertidal octopus fisheries. Below I outline a brief history of these fisheries in the southwest region.

Fin Fish: A lack of data on small-scale fisheries in southwest Madagascar poses challenges in predicting their status (Brenier et al., 2011; Le Manach et al., 2012; Gough et al., 2020). There are now several isolated studies which indicate unsustainable fishing (Davies et al., 2009; Brenier et al., 2011; Gough et al., 2020), including reports of declining catches from local fishers (Lemahieu et al., 2018). However, an accurate understanding of long-term trends is hindered by variations in research methodologies, study sites, fishing environments (e.g., coral reefs, sandy coastal areas), and gear types (e.g., net, long line, hand line, gill net, seine fishing). Furthermore, studies have primarily focused on the past three decades (but see Lagouin, 1959), potentially overlooking fisheries decline that began before that period and making it difficult to establish a sustainable reference level for fishing pressure (Zamborain-Mason et al., 2023).

When examining these studies collectively, a noticeable drop in catch per unit effort (CPUE) is evident between the 1960s and 1980s. Subsequently, CPUE has either remained relatively stable or increased (Table 3.1). For instance, in Toliara Bay, Lagouin (1959) reported frequent catches of one metric tonne using gillnets in the 1960s. In 1989/1990, Laroche and Ramananarivo (Laroche and Ramananarivo, 1995) reported CPUE values of 4.8 ± 0.4 , 6.7 ± 1.8 , and 8.2 ± 1.9 kg/fisher/trip for line, gillnet, and seine fishing, respectively. Brenier et al. (2011) reported comparable or increased CPUE values for the same region. They documented perceptions from reef users indicating a decline in marine resource quantity, fish size, and CPUE over the preceding three decades. Several authors attribute the increase or stability of catch rates to increased fishing effort, gear diversity, and technological advancements (Gough 2020, Brenier 2012, Gough et al 2021).

Trophic level of fish catch and fish size have also been used to investigate the status of small-scale fisheries in Madagascar. Gough et al. 2022 reported that the median trophic level of fish catch had decreased from 4.0 to 3.65 between 1997 and 2011. Similarly, Davies et al. (2009) reported trophic levels ranging from 2.6 to 3.67. These

trophic scores align with those observed in other overexploited fisheries in the Western Indian Ocean region. In a recent study, Gough et al. (2020) observed that a significant proportion of fish, in some instances up to 100%, were being captured before reaching maturity, strongly suggestive of overfishing.

Table 3.1 A summary of reported catch per unit effort from studies of small-scale fisheries in southwest Madagascar between 1958 and 2007

Date	Location	Line (kg/fisher/trip)	Gillnet (kg/fisher/trip)	Seine (kg/fisher/trip)	Reference
1958	Toliara Bay	Up to 100kg	1000 (kg/trip)	-	Lagouin, 1959
1989/1990	Toliara Bay	4.8 ± 0.4	6.7 ± 1.8	8.2 ± 1.9	Laroche and Ramananarivo, 1995
2006/2007	Toliara Bay	6.3 ± 0.5	7.9 ± 0.7	9.4 ± 0.8	Brenier 2012

Octopus: A review of octopus fisheries on the African continent indicates that there was a decline in total catches between 1990 and 2012 by approximately 40% (Roccliffe and Harris, 2015). Similar to fin fish, there is a lack of long-term catch data for octopus fisheries in southwest Madagascar. Before 2003, octopus fisheries were predominantly for subsistence and regional trade with commercialisation limited due to lack of refrigeration and transport (Westerman and Benbow, 2013). Following the arrival of an international exporter in 2003, large-scale commercial demand dramatically increased catch rates (L'Haringdon, 2006). Within the study region, temporary fishery closures have been demonstrated to have a positive impact on octopus landings (Benbow et al., 2014). However, a stock assessment of octopus fisheries from 2015 to 2020 indicates that octopus fishing was undertaken at mostly sustainable rates from 2015 to 2017 but from 2018 to 2020 was operating above maximum capacity (Roa-Ureta, 2022).

3.4 The Vezo People of Madagascar

Riake igne ty nivakiae ty vezo maso

The first opening of the Vezo's eyes is on the sea

Vezo Proverb

The southwest coast of Madagascar is the home of the Vezo people. The term Vezo means “to paddle” or “people who struggle with the sea and live on the coast” (Astuti, 1995a), encapsulating the fundamental role that the ocean plays in Vezo society. One is not born Vezo, but becomes Vezo by learning the skills to make a livelihood from the sea (Koechlin, 1975; Astuti, 1995b). Koechlin (1975) describes the Vezo as “semi-nomadic”. Vezo will often have a permanent residence within a village but may migrate to campsites for seasonal fish migrations and resource scarcity (Cripps and Gardner, 2016). In recent decades, the commercialisation of small-scale fisheries has altered migration patterns, with some groups choosing a more sedentary lifestyle, while others travel to marine resource frontiers located up to 500km away in search of valuable species such as shark and sea cucumber (Muttenger, 2015).

Vezo still today continue to employ traditional wooden canoes known as *laka* (often referred to as “pirogues” in English). These out-rigger canoes are dug out from the trunk of a single *Givotia madagascariensis* tree (Grenier, 2013). They can range from two to eight meters in length and are navigated using their square sails or by paddling with short wooden paddles. Predominant fishing techniques and preferred fishing areas traditionally differ between adult men and women, although cross-over does occur. Men predominantly use pirogues to fish in the intertidal zone at high tide and the subtidal zone using a range of fishing techniques including lines, nets, spears and spearguns (Gough et al., 2009). Freediving, often using a mask and occasionally scuba fins, is commonly employed to place nets or when using spears (A. Carter, Pers Obsv). Male fishers target a wide range of fin fish and target species vary depending on local coastal habitats (Gough et al., 2009; Brenier et al., 2011). In Velondriake, reef-associated species represent 30% to 50% of target species (Blue Ventures, unpublished data). In contrast, women and younger children engage in ‘gleaning’ in the intertidal zone. Gleaning refers to walking/wading on the reef to

collect marine organisms and is generally limited to the period of low spring tides. This period ranges from 4 to 7 days per month every fortnight, depending on the season (G. Manahira, Pers Comm). Gleaning is done by hand, or with long sticks or spears. When gleaning on the reef flat, women predominantly target invertebrates including octopus, sea cucumber, urchins and shellfish (Gough et al., 2009; Westerman and Benbow, 2013).

Wild caught marine resources remain central to livelihoods and food security in Velondriake (Barnes-Mauthe et al., 2013). However, in response to declining fish catch, initiatives to reduce reliance on wild fisheries have been undertaken. These efforts are supported through collaborations between NGOs and private companies. Such partnerships have spearheaded the establishment of sea cucumber aquaculture and seaweed farming in several villages in Velondriake (Vincent and Morrison-Saunders, 2013; Gardner et al., 2020). Beyond marine-related endeavours, other traditional livelihood activities include herding zebu cattle, hunting small mammals such as bushpigs (*Potamochoerus larvatus*) and tenrec (*Tenrecidae sp*), foraging fruits and small-scale farming (Douglass and Rasolondrainy, 2021).

Vezo society places great emphasis on oral traditions, storytelling, cultural practices and music which serve as important mechanisms for passing down knowledge and traditions (Astuti, 1995a; Langley, 2012; Douglass, 2023). Through oral histories, Vezo communities have a long-term archive of observational data about environmental conditions (Douglass and Rasolondrainy, 2021) and a rich understanding of complex social-ecological processes driving marine resource decline (Lemahieu et al., 2018). As such, supporting the integration of this knowledge for evidence to inform the design and implementation of co-management interventions presents a significant opportunity for locally-led development solutions.

3.5 Historical Context of Marine Conservation in Madagascar

Understanding the complexities of marine conservation and marine resource management in Madagascar requires an examination of the social and political history (Corson, 2017). A western scientific approach to marine resource

management was first established when the country became a French colony in 1897. By 1930, Madagascar had one of the most complete legislations concerning fisheries of all the French colonies (Petit, 1930). The approach was heavily influenced by the burgeoning field of fisheries science and policy from Europe and North America (Baker-Medard, 2020). This contrasted with traditional social-ecological relationships of the Malagasy people with their environment which were profoundly influenced by cultural practices and strong social-ancestral bonds (Ratsimbazafy et al., 2008; von Heland and Folke, 2014). In Vezo culture, for instance, the spirits of the sea manifest themselves in various forms, such as landscapes, trees, human hosts, or marine mammals like dugongs (Baker-Medard, 2020; Muttenger and Andriamahefazafy, 2021). These spirits are acknowledged through taboos, offerings, and sacrifices (Astuti, 1995a). The colonial era in Madagascar saw the start of marine conservation policy to maximize resource extraction which led to measures that are common today such as gear restrictions, temporary fishery closures, organism-specific size limits, and limits on the number of fishers (Billé and Mermet, 2002; Baker-Medard, 2020). These conservation practices often ignored or marginalized cultural connections to the environment (Baker-Medard, 2020). For example, Malagasy and French users would face different regulations, such as those concerning oyster and sea cucumber harvesting, as well as permits for whale hunting. A further colonial motivation for marine conservation was to protect 'exotic' or charismatic species such as sea turtles or dugongs primarily through moratoria on species or permanent no-take zones (Baker-Medard, 2020).

During the colonial period, the implementation of marine conservation measures varied across regions, as evidenced by oral history interviews conducted by Baker-Medard (2020). These interviews revealed more oppressive narratives from coastal villages in the northwest and northeast compared to those in the southwest. This discrepancy aligns with stories of the historical resilience of the Vezo people, who resisted complete control by pre-colonial rulers and French colonisers due to their nomadic lifestyle and ability to retreat to the sea when threatened (Poyer and Kelly, 2000; Tucker, 2004). Additionally, the arid conditions in the south of Madagascar discouraged European settlement and land appropriation (Cole and Middleton, 2001)

In the decades following its independence in 1960, Madagascar became an international focus for biodiversity conservation (Scales, 2014). Efforts were focused almost entirely on the terrestrial realm, demonstrated by the release of the National Environmental Action Plan (NEAP) in 1988 which did not mention marine policies. The NEAP, shaped by negotiations involving the World Bank, USAID and Madagascar's government, provided a framework for structural adjustments and foreign aid integrating development approaches (Kull, 2014). As a consequence, the government was compelled to conform to donor priorities in the allocation and implementation of funding environmental initiatives which focused on biological inventories, identification of conservation priorities and expansion of protected areas (Corson, 2017). This period was characterised by 'fortress conservation', that is the exclusion of local populations from the management of natural resources (Froger and Méral, 2012). Coastal areas were only identified as a priority in the second iteration of the NEAP in 1995 (Billé and Mermet, 2002). Marine policies at this time were heavily influenced by the terrestrial fortress approach. For example, the first two of the three MPAs created between 1989 and 1997 were created using top-down terrestrial protected area based procedure with little emphasis on community consultation (Cinner et al., 2009). In 1996, the first legal framework to introduce the decentralisation of natural resource management among users was created, known as Gestion Locale Sécurisée (GELOSE). The GELOSE integrated local by-laws (*dina*) with governmental laws allowing communities to develop their own regulations for resource use and management as long as they were in line with national policy (Antona et al., 2004).

In present-day Madagascar, there has been a notable shift towards community-centred management, evidenced by the establishment of over 200 LMMAs (Mihari and Ralaimihoatra, 2022). This network heavily relies on NGOs for financial and technical support (Mayol, 2013). While the intentions of these NGOs are generally positive, the resulting dependencies can echo historical power dynamics (Scales, 2014). Part of the issue lies in the funding mechanisms of NGOs, which often operate on short-term cycles dictated by donor interests rather than the long-term needs of the communities they serve (Aldashev and Vallino, 2019). Consequently, NGOs are required to continually innovate and re-market projects rather than focus on implementation and long-term capacity building in the local community (Gardner

et al. 2020). Moreover, the social memory of colonial-era marine resource regulations can shape people's perceptions of contemporary marine policies and the involvement of foreign NGOs. For instance, research by Baker-Medard et al. (2020) illustrates how the experiences of older fishers during the colonial period in Madagascar influenced their attitudes towards present-day marine conservation objectives and their willingness to engage with them.

While there has been a positive shift towards local conservation leadership in Madagascar, it remains crucial to contextualise conservation efforts within the historical social and political landscape. At the intersection of conservation and academic research, dismantling colonial legacies will require collaboration between researchers and practitioners, transdisciplinary work between academic disciplines (e.g. biologists, anthropologists, economists) and most importantly collaboration with local communities (Scales, 2014).

3.6 Blue Ventures

The research in this thesis was undertaken in collaboration with the marine conservation NGO, Blue Ventures. Blue Ventures was established in 2003 and now works to rebuild tropical fisheries and support coastal communities in 16 countries. It employs a comprehensive approach that integrates environmental, social, and economic strategies. Its primary objectives include securing access rights for fishers, fostering locally-led marine management initiatives, promoting sustainable fishing practices, developing alternative ocean-based livelihoods and integrating community health and education programs. Blue Ventures' inaugural project site was Velondriake. This presents an excellent opportunity to investigate how Blue Ventures' initiatives have impacted the resilience of coastal communities. Recognising its roots as a UK-based organisation, it is important to acknowledge Blue Ventures' positionality within the historical and social context of Madagascar.

First, Blue Ventures has been instrumental in driving the widespread adoption of LMMA in Madagascar, striving to empower fishing communities by securing access rights and decision-making powers. Today, Blue Ventures' management in Madagascar is almost entirely Malagasy and operates with considerable autonomy

from the UK head office. However, when Blue Ventures first began operations in Madagascar, the management team was predominantly European. Although this is no longer the case, the legacy of past power dynamics and decision-making processes likely continues to influence relationships both within the organisation and with local communities.

Second, the LMMAs which Blue Ventures support such as Velondriake remain reliant on Blue Ventures for essential financial support. In the context of severe poverty and disenfranchisement in southwest Madagascar, Blue Ventures has provided financial and development opportunities for nearly two decades. Therefore an "exit strategy" in the medium term where there are no negative implications for local communities is unrealistic (Gardner et al., 2020). Donor funding remains critical for the ongoing costs of the Velondriake LMMA. As a result, Blue Ventures must navigate a delicate balance, ensuring that it provides the necessary financial and technical support to align programs with donor interests, while also avoiding the overshadowing of local leadership and perpetuation of power imbalances reminiscent of conservation funding in Madagascar during the 1990s.

Thirdly, there can be divergent priorities between NGOs like Blue Ventures and the local communities they aim to support. Blue Ventures acknowledges this tension as the "conservation commitment conundrum", wherein potential long-term economic benefits from conservation efforts may not align with the critical short-term economic and food security needs of communities. In recognition, Blue Ventures supported management strategies that provide economic benefits on short timescales such as temporary closures of octopus fisheries (Blue Ventures, 2017). However, the economic advantages of other management measures, like coral reef no-take zones or gear restrictions, may not be realised in the short term and may pose a greater opportunity cost to local communities. This aspect becomes particularly significant when considering that fisher communities may prioritise the financial opportunities associated with Blue Ventures over the environmental interventions themselves (Gardner et al., 2020). Understanding this dynamic is crucial when investigating social-ecological issues, as it is likely to shape the perspectives of local stakeholders when engaging with research and activities affiliated with Blue Ventures.

3.7 Velondriake Locally Managed Marine Area

The research in this thesis is predominately based in villages and ecosystems located in the Velondriake Locally Managed Marine Area. The first co-management actions in Velondriake were in 2004, with a trial temporary fisheries closure for octopus supported by Blue Ventures and the Wildlife Conservation Society (Harris, 2007; Benbow et al., 2014). The success of this initial trial period prompted neighbouring villages to replicate the model and within two years, 24 villages were engaged in participatory management of local inshore ecosystems (Gardner et al., 2020). As of 2023, there are 32 villages in Velondriake along a 45km stretch of coastline. The LMMA is governed by the Velondriake Association (VA) made up of representatives from each village with technical support and resources provided by Blue Ventures. Velondriake is regulated by local by-laws called the *dina*. The *dina* is applied at village level but can be escalated to the VA and the magistrates' court if it cannot be settled locally (Andriamalala and Gardner, 2010). 06/06/2024

16:24:00Madagascar does not have a legal framework to formally recognise LMMAs. However, Velondriake was gazetted as a protected area in 2015 and therefore recognised at national level. Additionally, Velondriake is also part of the MIHARI network, an initiative of 18 LMMAs in southwest Madagascar collaborating to build local capacity, exchange best practices and improve financial sustainability. The Malagasy government now includes MIHARI in national level fora and decision-making processes (Rakotondrazafy, 2021).

As the Velondriake LMMA has evolved, it has included a growing number of practices. This includes permanent no-take zones in five coral reef sites, two mangrove sites and most recently two seagrass areas (Gilchrist et al., 2020; A. Carter Pers. Obsv.). These are contained within a 640 km² area stretching from the shoreline to approximately 15km offshore. Within this area, the *dina* prohibits industrial-scale fishing, destructive fishing methods including beach seining and poison fishing, as well as the fishing of turtles, dolphins and whales (Gilchrist et al., 2020). There are also numerous temporary closure sites, primarily on reef flats for octopus. Blue Ventures also leads health and education programmes and supports the development of livelihood strategies, including seaweed aquaculture, sea

cucumber aquaculture and ecotourism (Gardner et al., 2020). Further background and context are provided for Velondriake where relevant in the research chapters.

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Chapter 4: Cyclone impacts on coral reef communities in southwest Madagascar



A coral reef in the Velondriake Locally Managed Marine Area
Image: ACarter

4 Cyclone impacts on coral reef communities in southwest Madagascar

The following chapter “Cyclone Impacts on Coral Reef Communities in Southwest Madagascar” has been published in *Frontiers in Marine Science*. See Appendix 1.1 for the manuscript abstract, data availability statement and acknowledgements.

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Author Contributions: AC and HG conceived the idea. HG and CGa were involved in data collection. AC led data analysis with input from KD. AC wrote the first version of the manuscript with input from HG. HG, KD, CGa, CGo, SR, and AMWW reviewed and/or contributed revisions to the manuscript text.

4.1 Chapter Foreword

Madagascar is among the ten countries most exposed to cyclonic disasters in the world (Zy Misa Harivelo et al., 2022), and is the most exposed in Africa (Ghosh et al., 2022). In cyclone-exposed regions, cyclones have an integral role in the natural dynamics of coral reefs (Harmelin-Vivien, 1994). However, when combined with an increased frequency of marine heatwaves and anthropogenic pressures (e.g. overfishing), the recovery and regeneration of reefs between cyclone events is hindered (Eddy et al., 2021). In recent decades, tropical cyclones have been identified as one of the greatest causes of coral reef decline (De’ath et al., 2012) and triggers for ecological phase-shifts (Hughes, 1994). Decrease in coral cover has been associated with significant decrease in coral reef capacity to provide ecosystem services (Eddy et al., 2021). Furthermore, climate change is predicted to increase the frequency of intense tropical cyclones (Knutson et al., 2021) and thus their potential to damage reefs. Given their dependence on reef resources, coastal communities in southwest Madagascar are highly vulnerable to the ecological impacts cyclones have on the reef ecosystem. Yet, prior to this study, no peer-reviewed research was available of cyclone impact on the coral reefs in Madagascar.

Increasing the resilience of coastal communities to global change requires an understanding of how environmental disturbances (e.g. cyclones) alter ecosystem function (Thomas et al., 2019; Thiault et al., 2020). To understand how cyclones may influence the social-ecological systems of coastal communities in southwest Madagascar, it is vital to understand the local-scale ecological impacts. Thus, providing insight into how local management measures can support reef recovery and the social-ecological services provided by coral reefs (Beeden et al., 2015; Sato et al., 2018; Price, Brae et al., 2021).

In this Chapter, I address Research Objective 1 of this thesis using a cyclone event as an example to investigate the impact of a climate disturbance on the coral reefs in the Velondriake LMMA. The published manuscript focuses on the ecological impact and disturbance dynamics of the cyclone. In Section 4.7 I provide further discussion about the potential implications of our findings to inform marine management measures and support sustainability of coral reef social-ecological systems.

Start of published manuscript

4.2 Introduction

Coral reefs provide habitat for a third of marine species (Pandolfi et al., 2011) and supply ecosystem services for millions of people worldwide (Woodhead et al., 2019; Eddy et al., 2021) including food provision (Cohen et al., 2019), tourism and recreation (Spalding et al., 2017), and coastal protection (Ferrario et al., 2014). Tropical cyclones (also known as typhoons and hurricanes) are a major natural disturbance to coral reefs and can impact the structure and functioning of reefs at different spatial and temporal scales (Cheal et al., 2017). Ocean warming is predicted to shorten the return interval for strong tropical cyclones (Knutson et al., 2020), increasing their potential to have severe ecological impacts on coral reef ecosystems (Puotinen et al., 2020).

Direct impacts of cyclones on reefs are caused by large waves and currents exerting strong mechanical forces (Madin et al., 2014; Perry et al., 2014). Mechanical reef damage is highly variable and can range from minor fragmentation of coral branches

to the dislodgement of entire colonies (Bozec et al., 2015). Indirect impacts of cyclones include intense rainfall and high river loads, which can increase turbidity and decrease salinity on reefs leading to a stress response and mortality of coral organisms (Haapkylä et al., 2013; Perry et al., 2014). High river loads and coastal run off can also lead to the deposition of litter, potentially increasing the likelihood of coral disease (Lamb et al., 2018). Furthermore, increased nutrient availability from land run-off or strong winds bringing up nutrient rich water from depth can cause macroalgal blooms that inhibit coral recruitment (Kuffner et al., 2006; Doropoulos et al., 2014).

The spatial distribution of cyclone damage to coral communities is characteristically patchy (Harmelin-Vivien, 1994). Factors which influence the spatial heterogeneity of cyclone damage include the intensity of waves and their duration near a particular reef; the location, topography and depth of a reef; and the composition and state of the coral community (Mumby, 1999; Fabricius et al., 2008; Beeden et al., 2015; Price et al., 2021). Several studies have aimed to model predictors of cyclone damage (e.g. Puotinen, 2005; Fabricius et al., 2008; Puotinen et al., 2016, 2020). The simplest models use distance from the cyclone track as a predictor of damage severity (Edwards et al., 2011; Ban et al., 2015). However, using distance thresholds alone can be ineffective, as evidenced in storms where severe damage has occurred up to 800 km from the cyclone track (Puotinen et al., 2020). An alternative approach is to include the cyclone parameters, wind speed and duration of cyclone winds (Puotinen, 2007; Woolsey et al., 2012; Price et al., 2021). These can be used as a proxy for the intensity of cyclone-generated waves (Puotinen, 2005) and can help delineate the region in which cyclone damage would be likely (Puotinen, 2007). All studies agree that any model of cyclone impact using only cyclone parameters is not likely to capture the heterogeneity of damage. This is because, at a regional scale, bathymetric and topographic features such as reefs and islands will interact with wave intensity (Young and Hardy, 1993). Within reefs, factors including depth and reef profile cause variability in reef exposure (Woesik et al., 1991). Finally, the vulnerability of coral colonies will differ according to their size and shape. Large colonies and colonies with fragile morphologies are generally more vulnerable to wave damage than smaller colonies with sturdier growth forms (Muko et al., 2013; Madin et al., 2014).

Cyclones can change the supply of ecological goods and services provided by the reef ecosystem (Micheli et al., 2014). Direct impacts of cyclones may change the movement and behaviour pattern of fish species (Kawabata et al., 2010), influencing their availability to fishers (Tobin et al., 2010). Cyclone-associated reduction in the three-dimensional structure of the reef, hard coral cover and coral diversity can decrease the number and variety of habitats available for reef fish (Graham and Nash, 2013; Komyakova et al., 2013). Where major structural changes occur, they will likely have long-term effects on the abundance and diversity of reef-associated species (Bozec et al., 2015; Darling et al., 2017; Pratchett et al., 2018). In coastal communities with strong livelihood dependency on reef fisheries, unpredictability of catch may impact food and income security (Hicks et al., 2021). Madagascar has been identified as a country highly vulnerable to the degradation of coral reefs owing to its significant economic and social reliance on reef resources (Cinner et al., 2012). This is particularly relevant along the southwest coast, where aridity and poor soils limit opportunities for agriculture (Hanisch, 2015), and where there are few other economic or subsistence alternatives to fishing (Barnes-Mauthe et al., 2013). The southwest coast of Madagascar is home to the sea-faring Vezo people (Marikandia, 2001). Vezo are highly reliant on the reef-associated fisheries for their income and food security (Barnes-Mauthe et al., 2013), and the cultural identity of the Vezo is also entwined with the ocean; you are not born Vezo, you become Vezo as you learn skills to master and live off the sea (Astuti, 1995). Preserving coral reefs in this region is vital for the preservation of Vezo livelihoods, food security, culture and identity (Astuti, 1995; Barnes-Mauthe et al., 2013)

The documentation of cyclone impacts on coral reefs is an important precursor to ongoing climate adaptation efforts and locally tailored conservation planning, particularly where reliance on coral reefs for food security and livelihoods is high. However, studies assessing the impacts of cyclones on coral reefs are spatially biased. In particular, few studies are available on the impact of cyclones in the Western Indian Ocean (WIO; but see Letourneur et al., 1993; Naim et al., 2000; Scopélitis et al., 2009) and no studies have been found for Madagascar. Here, we present the first published study on the impact of a tropical cyclone on coral reefs in Madagascar. On 22nd February 2013, Cyclone Haruna, a category 3 storm on the Saffir-Simpson scale - with maximum sustained wind speeds of 150 kmh⁻¹ and gusts

of up to 185 kmh^{-1} - made landfall on the southwest coast of Madagascar, in the Velondriake Locally Managed Marine Area (LMMA). We use existing data (2011 – 2015) from a long-term, citizen science reef monitoring programme to investigate the impact of Cyclone Haruna on the coral community at a total of 21 reef sites in Velondriake LMMA. The objectives of this research were to: (a) quantify changes in benthic cover and benthic composition following Cyclone Haruna and (b) examine the influence of cyclone parameters (duration of cyclone impact, wind speed and minimum distance from cyclone track) and environmental variables (reef type and reef depth) on the severity of cyclone impact. This study aims to increase our knowledge of reef system vulnerability to severe storm impacts in the WIO and therefore help improve understanding of climate change-associated threats on the livelihoods of coastal communities.

4.3 Methods

4.3.1 Study region

The study was conducted in southwest Madagascar within the Velondriake LMMA ($43^{\circ}13'30 \text{ E}$, $22^{\circ}04'22 \text{ S}$), 150km north of the regional capital of Toliara (Figure 4.1). The Velondriake LMMA stretches along 40km of coastline, incorporating 35 coastal villages with a combined population of approximately 8000 people (Blue Ventures unpublished data, 2016; see Gardner et al., 2020 for further information on Velondriake). For those living in the LMMA, seafood provides 99% of protein, and 87% of the adult population derive their livelihoods from small-scale fishing (Barnes-Mauthe et al., 2013).

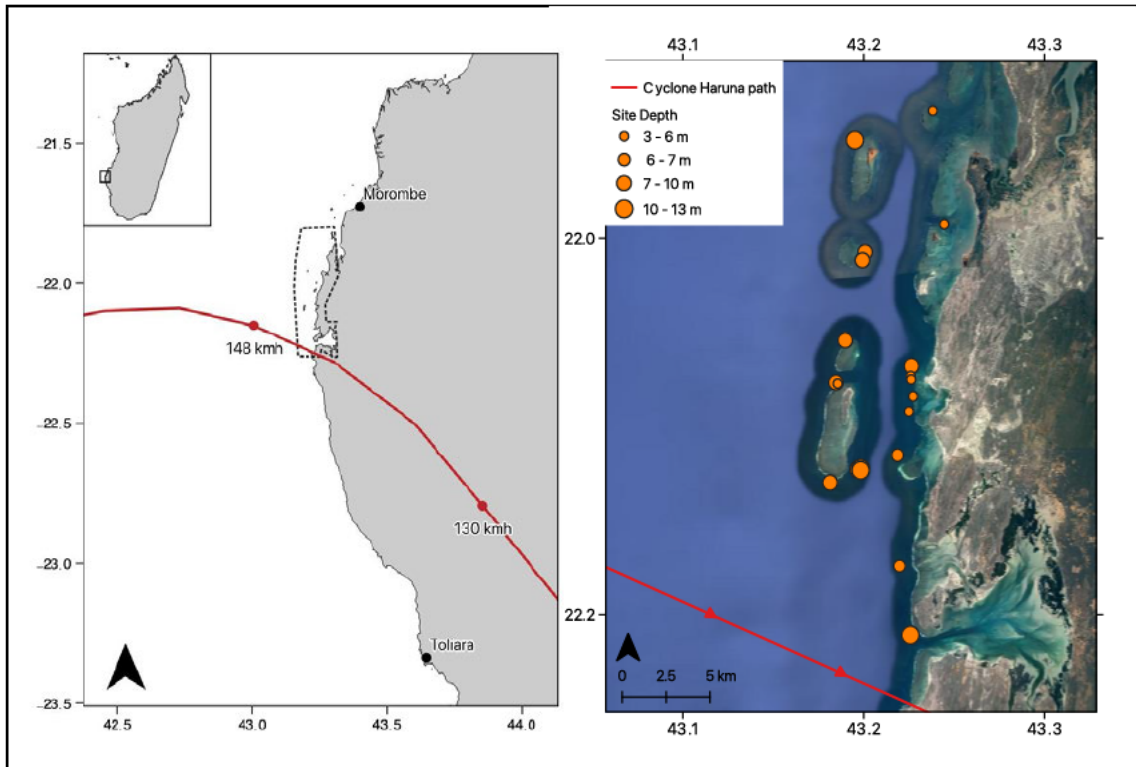


Figure 4.1 (A) The position of the study region in relation to the path of Cyclone Haruna on the 22nd Feb 2013. The dotted line is the boundary for the Velondriake Locally Managed Marine Area. (B) The location of reef sites in relation to the path of Cyclone Haruna. Reef depth is indicated by the size of the orange circles.

The marine area of the Velondriake LMMA covers approximately 600 km². The reef complex in the LMMA is characterised by a fringing and barrier reef system with several patch reefs situated in a 5km wide channel. The region has relatively high annual variation in sea surface temperature (McClanahan et al., 2009) with a range of up to 11° C recorded (22-33 ° C in 2015; Blue Ventures, unpublished data) and the presence of large, anticyclonic eddies, caused by the interaction of the south equatorial current with the Madagascar landmass (Quartly and Srokosz, 2004). The distinctive oceanographic climate has resulted in a biogeographically unique reef assemblage that includes corals endemic to Madagascar such as *Pocillopora fungiformis* and *Stylophora madagascarensis* (Veron, 2002), and 430 species of reef fish (Nadon et al., 2008).

4.3.2 Survey methodology

Survey Sites: Coral surveys were undertaken between 2011 and 2015 as part of a long-term citizen science reef monitoring programme run by the NGO Blue Ventures (www.blueventures.org) in the Velondriake LMMA. The survey programme was designed to monitor the health of coral reef ecosystems over time across the LMMA as a whole. Surveys took place on reef sites comprising patch, fringing and barrier reefs of varying depths, spread across the north, central and southern parts of Velondriake. As part of our data preparation, we selected a subset of the Blue Ventures dataset, including the sites that had data available up to two years before and after Cyclone Haruna. This resulted in the inclusion of 21 sites in total (11 patch, 5 barrier and 5 fringing reefs) with a depth range of 3 -13m (Figure 4.1). Sites were surveyed between one and three times per year. Benthic data was not available at every site, each year. Sites included in each analysis are outlined in Appendix 1.2 and 1.3. The following outlines the survey methodologies used by the Blue Ventures teams.

Adult coral community: Point Intersect Transects (PITs) were used to survey hard coral cover (HCC) and the morphology of adult corals (>10cm in diameter). Transects were placed randomly at each site running east to west for all patch reefs and west-facing sites and, north to south for south facing sites. The number of transects undertaken ranged between 6 and 30 and was determined by the size of the site. One observer per transect made fifty observations at 20 cm intervals along each 9.8 m transect: the first being at 0.0 m and the fiftieth at 9.8 m. The type of benthic organism or substrate at each point was identified. Hard corals were recorded by their morphology (branching, digitate, tabular, foliose, encrusting, massive, solitary or columnar). In addition, quadrat surveys were used to assess the community assemblage of adult corals following the methods in McClanahan (2004). Seven randomly positioned 4 m² quadrats were completed at each site. The quadrats were haphazardly placed by the observer who randomly selected a direction of travel and a random amount of fin kicks (between 5 and 20) to determine the quadrat location. All colonies with diameter >10 cm were counted in each quadrat. Colonies were identified to genus level except for *Porites* which was

classified as either 'branching' or 'massive'. The sub-genus *Synarea* was included within *Porites*.

Coral recruits and juvenile corals: Coral recruits and juvenile corals ≤ 10 cm diameter were surveyed using 20 randomly placed 0.1 m² quadrats. Quadrat surveys were undertaken by two observers per quadrat. The size of each colony was measured to the nearest 0.5 cm and recorded to genus level.

4.3.3 Citizen science survey data validation

PITs have been identified as a time efficient survey method for monitoring disturbance over large reef areas with non-specialist surveyors (Facon et al., 2016). To ensure data accuracy, before undertaking PITs, the Blue Ventures citizen scientists underwent training in survey and identification of corals and other benthic life forms. To be eligible to undertake surveys, participants were required to pass a computer test and in-water identification tests with an accuracy rate of 90%. Following completion of these tests, participants undertook a PIT with a member of trained staff. On the PIT test, the participant's data had to be in 100% agreement with the data collected by the staff member when identifying major groups (e.g., between coral, algae, substrate), and citizen scientists had to correctly identify organisms within these major groups to at least 80% accuracy (e.g., branching or massive coral growth forms, calcareous or turf algae). Quadrat surveys of the adult coral community assemblage and the recruit community assemblage (where identifying to genus level was required) were undertaken only by trained field staff.

4.3.4 Cyclone parameters

We investigated the severity of cyclone damage in relation to three continuous cyclone parameters: (i) wind speed (average maximum wind speed when the cyclone was within 70km of the reef site in km/h), (ii) duration (the number of hours the cyclone was within 70km of the reef site) and (iii) distance (the minimum distance from the centre of the cyclone to the reef site in km). Wind speed and track data for Cyclone Haruna and historic cyclones in the region were extracted from the International Best Track Archive for Climate Stewardship (Knapp et al., 2010). Seventy kilometres was selected as the distance threshold as it is within the range

observed for severe damage following cyclone events of similar intensity to Cyclone Haruna (Manzello et al., 2007; Puotinen, 2007).

4.3.5 Statistical methods

Generalized linear mixed model (GLMM) analysis was used to assess variation of cyclone impact on (i) hard coral cover (ii) taxonomic richness (number of coral genera per site) and (iii) and recruit density (number of colonies <10cm diameter per m²). We divided the survey data into four time periods related to the date of the cyclone. We refer to the two years before the cyclone as year -2 (22nd February 2011 - 22nd February 2012) and year -1 (23rd February 2012 - 22nd February 2013) and the two years after the cyclone as year 1 (23rd February 2013 - 22nd February 2014) and year 2 (23rd February 2013 - 22nd February 2014). GLMM analysis of hard coral cover and recruit density included survey data two years before and two years after the cyclone. For taxonomic richness, data was available for only one year before and two years after the cyclone. GLMM analysis was selected to allow for the inclusion of fixed and random effects. Fixed effects included cyclone parameters wind speed, duration and distance and environmental variables reef type and reef depth (Appendix 1.2). We also included a fixed effect (before/after) for whether a survey was conducted before or after the cyclone occurred to quantify the overall impact of the cyclone on coral cover, taxonomic richness and coral recruits. The before/after term was allowed to interact with cyclone parameters to try and understand how exactly cyclones impact coral communities (Laird and Ware, 1982). We also included reef type and reef depth in interaction with the before/after term to determine if different reef environments were impacted differently by the cyclone. We examined Pearson correlation coefficients and Variance Inflation Factors (VIFs) to assess potential multi-collinearity between fixed effect variables. Wind and duration metrics were found to be strongly negatively correlated ($r = -0.83$ to -0.85). We therefore did not include both wind and duration in the same model and calculated VIF for the two potential subsets of predictors. The highest VIF for any fixed effect in all subsets of models was 1.15. In each model, site was included as a random effect. Observer identity was included as a random effect in models investigating taxonomic richness and recruit density.

We assessed whether model assumptions were followed using graphical procedures, evaluating homogeneity of variance by plotting residuals against each fixed effect and against fitted values. All numerical explanatory variables were scaled by standardisation to the same mean and variance in order to compare their relative effects on response variables. Taxonomic richness was modelled as a Poisson distribution with a log link function. Hard coral cover and recruit density were modelled as a negative binomial distribution with a log link function (poisson models for these variables were overdispersed). All models were fit using Laplace Approximation. For each of the GLMM analyses, null models (with no fixed effects), a model including only before/after as a fixed effect and all possible combinations of fixed effects in interaction with the before/after term were tested. Model performance was compared using Akaike's Information Criterion, corrected for small sample sizes (AICc; Akaike, 1974). The model with the smallest AICc value was considered the 'best' model and competing models were considered equivalent if $\Delta\text{AICc} < 2$. In addition to AIC, we used Likelihood Ratio Tests to compare the goodness of fit and test the significance of individual fixed effects when dropped from the best model.

The analysis of similarities (ANOSIM) test is a non-parametric test that can be used to assess for significant differences between the composition of different groups. ANOSIM was used to test if there is a significant difference between coral community composition before and after Cyclone Haruna. A one-way, pairwise ANOSIM based on Bray-Curtis distance on a square root transformed compositional matrix (species by survey) was conducted to determine the significance of differences in the (i) taxonomic composition of adult corals (ii) morphological composition of adult corals and the (iii) taxonomic composition of coral recruits, one year before and one year after Cyclone Haruna. Sites included in the analysis are listed in Appendix 1.3. The identification of which taxa and morphologies were most important at driving the differences pre and post cyclone were conducted using similarity percentage (SIMPER) analysis. Wilcoxon signed-rank test was used to assess if there was a significant difference in mean coral recruit size before and after the cyclone. The mean relative cover of coral genera and coral morphologies and the relative frequency of recruit size classes were calculated for each year as the number of colonies of each coral genera, morphology or recruit size class per site divided by the total number of observations at that site.

Analysis was conducted using the 'lme4' package (Bates et al., 2007) and the 'vegan' package (Oksanen et al., 2007) in R Version 1.0.143 (R Core Team, 2020)

4.4 Results

4.4.1 Hard coral cover

Mean coral cover in the study region was 37.8% (± 1.2 SE) in year -2 and 36.9% (± 1.1 SE) in year -1. During the first year after the cyclone (year 1), mean coral cover declined to 21.1% (± 0.9). Coral cover declined across all surveyed sites, but the extent of coral decline varied among locations from -1.4% to -45.8%. Two years after the cyclone (year 2) mean coral cover increased slightly to 23.0% (± 1.1 SE; Figure 4.2). However, recovery between years 1 and 2 was not observed at all sites and changes in coral cover ranged from - 11% to + 21.9%.

The most parsimonious models based on AICc values (Table 4.1) and Likelihood Ratio Tests (Appendix 1.4) contained the cyclone parameters duration and distance and the environmental characteristic reef depth, all in interaction with the before/after term (Appendix 1.5). The model results indicate that cyclone duration had a significant negative effect, with sites in the path of the cyclone for longer showing a greater decrease in coral cover. Distance and reef depth were also found to have negative effects, with sites located furthest from the cyclone track and sites at a greater depth having greater losses in coral cover after the cyclone. The difference between the marginal R^2 (0.21) and the conditional R^2 (0.56) of the best model indicates unexplained site-to-site variation in hard coral cover. Including wind speed and reef type in the models did not improve the model fit. Our best model slightly under-predicted hard coral cover where coral cover was highest, but overall we found a largely linear relationship between observed hard coral cover and that predicted by the model (Appendix 1.6 and 1.7). When we removed those surveys with the highest coral cover from the model, the same results are obtained with respect to which fixed effects are included in the best model and the directionality of their influence on hard coral cover. An additional analysis assessing proportional change in coral cover rather than raw coral cover values gave highly similar results with respect to duration, depth and distance (see Appendix 1.8).

4.4.2 Coral assemblage composition

A total of 53 coral genera were identified across all the surveys. Mean taxonomic richness was 18 (SE ± 2.12) one year before (year -1) and 16 (SE ± 1.50) one year after the cyclone (year 1; Figure 4.2). The most parsimonious models ($\Delta AIC < 2$) were the null model and one with the before/after term (Table 4.1). The before/after term was not significant, suggesting the cyclone did not consistently change taxonomic richness up or down. Including cyclone parameters (duration, distance and wind speed) and reef type and depth did not significantly improve the model.

The taxonomic and morphological composition showed a significant change when comparing one year before (year-1) and one year after the cyclone (year 1; Genera: ANOSIM, $R = 0.07$, $P < 0.05$; Morphology: ANOSIM; $R = 0.12$, $P < 0.05$). This dissimilarity was driven by changes in the abundance of the dominant coral taxa *Acropora*, *Pocillopora*, *Galaxea* and *Stylophora* (SIMPER: 18.0%, 9.3%, 5.5% and 4.9%, respectively) and branching, encrusting and massive morphologies (SIMPER: 34.4%, 20.4%, 8.1%, respectively). From surveys conducted before the cyclone, the relative cover of *Acropora* ranged from 10% to 55% between sites. The mean relative cover of *Acropora* across the region decreased slightly in the year following the cyclone. Other branching genera, *Pocillopora* and *Stylophora* also decreased in relative cover following the cyclone. Massive *Porites* had the greatest increase in relative cover (Figure 4.2). In the year following the cyclone, the relative cover of branching corals decreased from 34.2 % (± 3.05) to 24.34% (± 3.65) and encrusting and massive corals became the dominant morphologies (relative cover of 32.21 (± 3.00) and 28.34 (± 2.78) respectively; Figure 4.2).

4.4.3 Coral recruits

The greatest decrease in density of coral recruits was observed between the two years before the cyclone from 31.8 (± 2.08) recruits/m² in year -2 to 24.5 (± 1.93) recruits/m² in year -1 (Figure 4.3). In year 1 after Cyclone Haruna, the density of recruits continued to decrease to a mean of 20.5 (± 1.21) recruits/m². In the second-year post-cyclone, recruit density increased to above pre-cyclone levels (28.9 (± 2.22) recruits per m²). Using a negative binomial GLMM, several models were statistically equivalent ($\Delta AIC < 2$) and had limited predictive power (Table 4.1).

Likelihood ratio tests revealed adding cyclone parameters to the model did not improve the model accuracy ($p > 0.05$) and therefore the null model was assumed the best model.

The composition of coral recruits differed significantly one year before and after the cyclone (ANOSIM, $R = 0.11$, $P < 0.05$). *Acropora*, *Pocillopora* and *Favia* contributed most towards the dissimilarity (SIMPER; 9.2%, 8.3% and 7.0% respectively). *Acropora* was the dominant genus of recruits and after the cyclone, increased in mean relative abundance across the study region from 15.1% (± 1.5) to 17.0% (± 2.23). *Pocillopora* and *Favia* became less abundant and there was an increase in the relative count of massive *Porites*, *Psammacora* and *Seriatopora* (Figure 4.3). No significant change was observed in the mean size class of recruits following the cyclone (Wilcoxon signed-rank; $V=54$, $p > 0.05$: Figure 4.3)

Table 4.1 Hard coral cover (HCC), taxonomic richness and recruit density were modelled as a function of three cyclone parameters (i) wind (average maximum wind speed when the cyclone was within 70km of the reef site in m/s), (ii) duration (number of hours the cyclone was within 70km of the reef site) (iii) distance (minimum distance from centre of the cyclone to the reef site in km) and two reef characteristics (i) reef type and (ii) reef depth. A “before/after” (BA) interaction term was used to quantify the impact of the cyclone. Models are ranked in ascending order of AIC values, Δ AIC represents the difference in AIC between each model and the highest ranked model and K is the number of parameters. Cum.Wt represents the cumulative weight of each model. For HCC the best performing, the BA and null model are reported. Taxonomic Richness and Recruit Density models are reported to a cumulative weight of 0.95. Site is included as a random effect for HCC. Site and Observer are included as random effects for taxonomic richness and recruit density.

Response Variable	Fixed Effects	K	AICc	Δ AIC	Cum.Wt	Log Likelihood	R ² _{marginal}	R ² _{conditional}
Hard coral cover	<i>duration*BA + distance*BA + depth*BA</i>	11	9193.8	0.0	0.99	-4586.8	0.21	0.56
	<i>BA</i>	4	9263.6	69.9	1.00	-4627.8	0.16	0.53
	<i>null</i>	3	9602.4	408.7	1.00	-4798.2	0.00	0.36
Taxonomic richness	<i>null</i>	3	610.4	0.0	0.50	-302.1	0.00	0.53
	<i>BA</i>	4	612.4	2.0	0.69	-302.0	0.00	0.54
	<i>wind*BA</i>	6	613.3	2.9	0.81	-300.2	0.05	0.53
	<i>distance*BA</i>	6	615.1	4.7	0.85	-301.1	0.02	0.53
	<i>duration*BA</i>	6	615.6	5.1	0.89	-301.3	0.02	0.54
	<i>depth*BA</i>	6	615.8	5.3	0.93	-301.4	0.01	0.54
	<i>distance*BA + wind*BA</i>	8	616.6	6.1	0.95	-299.5	0.07	0.521
Recruit density	<i>BA</i>	5	894.1	0.0	0.22	-441.7	0.06	0.39
	<i>distance*BA</i>	7	895.1	1.0	0.35	-439.9	0.08	0.43
	<i>wind*BA</i>	7	895.3	1.3	0.47	-440.1	0.08	0.43
	<i>null</i>	4	895.6	1.6	0.57	-443.6	0.00	0.26
	<i>depth*BA</i>	7	895.8	1.7	0.66	-440.3	0.07	0.39
	<i>wind*BA + distance*BA + depth*BA</i>	11	895.8	1.7	0.75	-435.4	0.11	0.47
	<i>reef type*BA</i>	9	896.1	2.0	0.84	-438.0	0.10	0.48
	<i>wind*BA + distance*BA</i>	9	897.0	2.9	0.89	-438.5	0.09	0.46
	<i>duration*BA</i>	7	897.3	3.2	0.93	-441.0	0.07	0.41
	<i>distance*BA + duration*BA</i>	9	898.59	4.51	0.95	-439.28	0.09	0.44

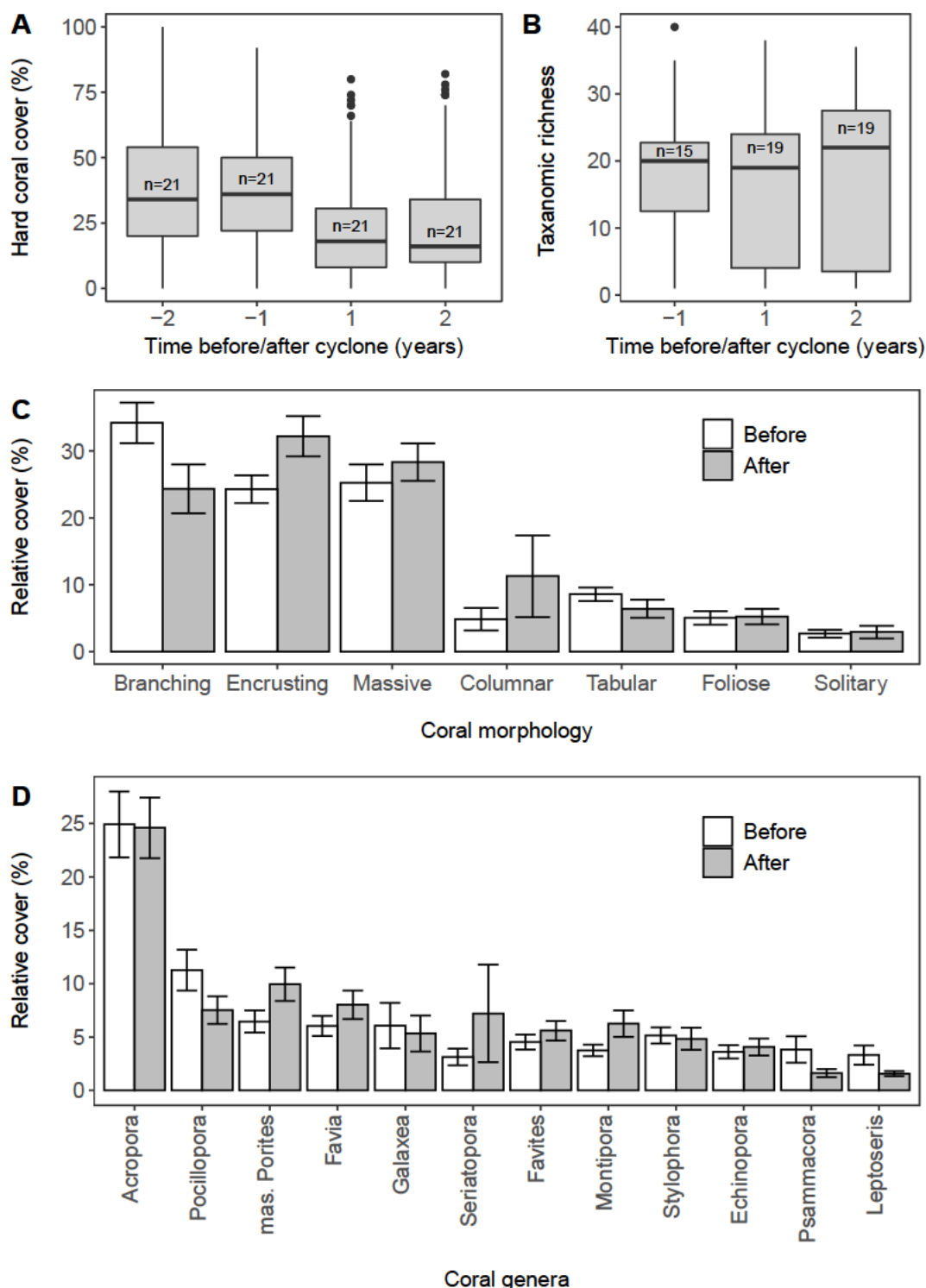


Figure 4.2 (A) Hard coral cover and (B) mean taxonomic richness (C) mean relative cover of coral morphologies and (D) mean relative cover of coral genera at reef sites in the Velondriake Locally Managed Marine Area before and after Cyclone Haruna (22nd February 2013). Values are for adult coral colonies with diameter >10cm. (A, B) The solid line in the box represents the median; the top and bottom of the boxes represent the 25th and 75th percentiles; the whiskers above and below the box extend no further than 1.5*the interquartile range; the dots represent outliers and (n) is number of sites. Values are for adult coral colonies with diameter >10cm. N is number of sites. (C, D) Values are for surveys within one year before and one year after Cyclone Haruna and bars are standard error.

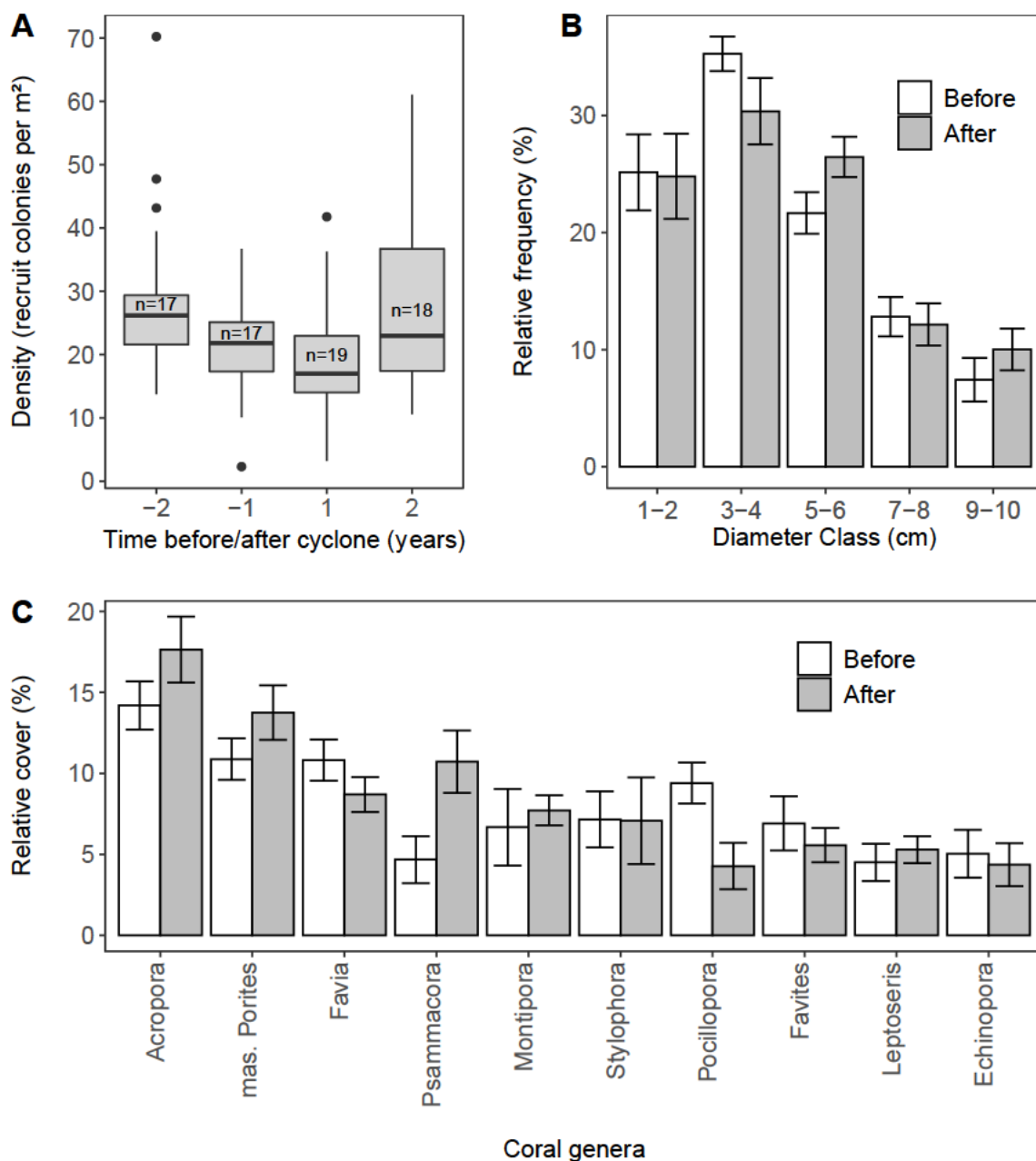


Figure 4.3 (A) Recruit density (B) relative frequency of recruit colony sizes and (C) relative cover of coral genera, for coral recruits and juvenile corals (colony diameter < 10cm) before and after Cyclone Haruna (22nd February 2013). (A) The solid line in the box represents the median; the top and bottom of the boxes represent the 25th and 75th percentiles; the whiskers above and below the box extend no further than 1.5*the interquartile range; the dots represent outliers and (n) is number of sites. (B, C) Values are for surveys within one year before and one year after Cyclone Haruna and bars are standard error.

4.5 Discussion

The present study found that Cyclone Haruna had a spatially heterogeneous impact on coral cover and the community composition of coral reefs located in the Velondriake LMMA in southwest Madagascar. Coral loss was greatest at sites with the longest duration of cyclone impact and at the deepest sites and sites furthest from the cyclone track. There was a significant difference in the taxonomic and morphological composition of the coral assemblage before and after the cyclone. Two years after the cyclone, hard coral cover increased, and the density of coral recruits increased to above pre-cyclone levels indicating potential for recovery of the coral population.

Patterns of taxonomic richness and recruit density were found not to be related to cyclone parameters and reef type was found not to have a significant influence on the impact of the cyclone. In addition, the high conditional R^2 relative to marginal indicates that there is site-to-site variation in hard coral cover which is not explained by the variables in the model. It is likely environmental variables not captured in our investigation, such as the orientation of reefs and the influence of localised topography on wave exposure, will have had some influence on the pattern of cyclone impact on the coral community (Woodley et al., 1981; Harmelin-Vivien, 1994; Mumby, 1999). Furthermore, when compared to other reports on cyclone impact on corals (e.g. Fabricius et al., 2008; Beeden et al., 2015; Price et al., 2021), this study covers a small region with relatively low variation in wind speed, duration of cyclone impact and distance from the cyclone track. Low variation in cyclone parameters could be a contributing reason as to why we did not find further significant relationships between the cyclone parameters and responses in the coral population.

4.5.1 Hard coral cover

Extreme winds and waves caused by cyclones dislodge and damage coral colonies causing a decline in coral cover (McLeod et al., 2019). Cyclone Haruna caused coral cover to decline in the Velondriake LMMA by a mean of 15.8% in the study region, but the spatial distribution damage was substantially patchy. A mosaic of impact

severity is typical of cyclone damage (Harmelin-Vivien, 1994; Guillemot et al., 2010; Perry et al., 2014; Cooke and Marx, 2015), as coral vulnerability is influenced by factors from local (Madin et al., 2012, 2014) to regional scales (Young and Hardy, 1993). No reports of cyclone impact of similar strength events are available for comparison in the WIO. Cyclone damage varies substantially between cyclone events and reef regions. However, the decline observed at the present study site is comparable to the severity of damage caused by category 3 Cyclone Rona (1999) on the Great Barrier Reef (16% decline in average HCC; Cheal et al., 2002) and the average reduction of coral cover caused by hurricanes in the Caribbean (17% decline on average HCC; Gardner et al., 2005).

Previous studies have found sustained wind speed, storm duration and distance from the storm track as effective predictors of coral cover loss (Puotinen, 2007; Fabricius et al., 2008). For Cyclone Haruna, the duration of cyclone impact, the distance from the cyclone path and depth of the reef were the most effective predictors of coral cover decline. Across the study region, reef sites were within 70km of Cyclone Haruna for between 18 to 24 hours. Reef sites within the threshold distance for a longer duration experienced more severe coral loss. The duration of cyclone impact at a reef site will impact the severity of coral loss as short exposure to high energy waves will only break or dislodge fragile colonies, while persistent exposure to high energy waves will have time to weaken and remove stronger and larger areas of reef framework (Puotinen et al., 2016). Reef depth and distance from the cyclone track modulated the effect of the cyclone on coral cover, with coral loss greater at deeper reef sites and reef sites located further away from the cyclone track. The maximum surveyed reef depth was 13 m, well within the range of which direct mechanical damage to a reef from a tropical cyclone has been observed (refs in Harmelin-Vivien, 1994). For this study, it is possible that more severe coral decline occurred on deeper reefs as they were generally located offshore, exposed to cyclone waves arriving from the open ocean. On the other hand, shallower reef sites located behind the offshore barrier may have been more sheltered as wave energy was dissipated by the barrier reef (Done, 1992; Fabricius et al., 2008). The destruction potential of waves that were generated from the cyclone as it crossed the inshore area are likely to have been limited by shallower depth and shorter fetch (Young and Hardy, 1993). Cyclone damage related to distance from the cyclone path

is often unpredictable as evidenced by corals located in the direct path of the cyclone remaining unchanged (Massel and Done, 1993), yet coral up to 800km away experiencing severe decline (Puotinen et al., 2020). All reef sites in the study region were located close enough to the cyclone track (between 8.7 km and 39.3 km) in which severe damage would be expected (Fabricius et al., 2008). It is likely that the pattern of coral decline was strongly influenced by localised topography producing refraction of storm waves (Harmelin-Vivien, 1994). The rate of damage would be higher at sites struck directly by cyclone-induced waves as opposed to those sheltered by an adjacent reef. As Cyclone Haruna crossed directly from offshore to inshore in the study region, the reefs were impacted by cyclone-induced waves from multiple directions, which may have produced complex patterns of damage that could not be captured in our model.

4.5.2 Coral assemblage composition

Cyclone Haruna did not significantly impact the taxonomic richness of the adult coral community in the study region. The relative difference of the cyclone impact on coral cover compared to taxonomic richness can be partially attributed to the fact that dominant branching morphologies reduced in cover but did not disappear (Rogers, 1993; Fabricius et al., 2008). Following the cyclone, the dominant coral morphology changed from branching to encrusting and massive. A loss of the more fragile coral morphologies (branching and tabular) can be expected from cyclone-induced damage, as they are more vulnerable to fragmentation or dislodgement from extreme waves (Baldock et al., 2014). At some sites, we detected an increase in the relative cover of *Acropora* in the year following the cyclone. This increase may be caused by fragmentation of existing *Acropora* colonies concurrent with the mortality of other genera. Over time, fragments can attach and fuse with underlying coral colonies or substrate and survive (Linares et al., 2011), but due to tissue damage or partial mortality, are also more at risk of mortality from secondary impacts such as bioerosion or fouling from macroalgae (Knowlton et al., 1981). In other cyclone events, mortality from secondary impacts has caused severe mortality rates of *Acropora* to be recorded from 5 months to over a year after a cyclone event (Knowlton et al., 1981; Muko et al., 2013), however, this does not seem to be the case within the Velondriake LMMA following Cyclone Haruna.

4.5.3 Coral recruits

Following declines in coral cover after a disturbance, the survivorship of coral recruits will play a key role in the structuring of the future adult coral assemblage (Coles and Brown, 2007). We observed the greatest decrease in recruit density in the two years before Cyclone Haruna. Interannual variability in recruit density relative to adult coral cover may occur as small individuals can be dislodged or killed outright by biotic (Doropoulos et al., 2014) or abiotic factors (Edmunds et al., 2010) that cause larger individuals only partial or no mortality (Babcock, 1991). Recruit density continued to decrease at some sites in the year following Cyclone Haruna, although we found no significant impact of the cyclone across the region. From our data, it is not possible to extrapolate the influence of Cyclone Haruna compared to other biotic and abiotic pressures on recruit density. Compared to adult coral cover, the relationship between cyclone parameters (wind speed, distance from cyclone track and duration of cyclone impact) and coral recruits may be less pronounced as small colonies will have significantly less drag than their adult counterparts (Harmelin-Vivien, 1994). It is also likely that parameters not captured in our model, such as local scale topography and reef rugosity provided localised shelter for smaller colonies, creating a mosaic of impact severity at an intra-reef scale.

Following the cyclone, observations indicate an increase in macroalgae cover (Blue Ventures, unpublished data). In other regions, algal blooms caused by severe storms have been linked to the failure of coral recruitment and survivorship, as recruits can be outcompeted by the algae for suitable settlement substrate (Baldock et al., 2014; Doropoulos et al., 2014). However, following Cyclone Haruna we found no significant difference in the relative abundance of recruit size classes (1-10cm) and two years after the cyclone recruit density increased to above pre-cyclone levels. This suggests macroalgae did not inhibit the survivorship of recruits which had settled before the cyclone or the settlement of new arrivals.

The taxonomic composition of coral recruits was significantly different following Cyclone Haruna. There was an increase in the relative abundance of sturdier genera including *Porites* massive, *Psammacora*, and *Montipora*. This increase can likely be attributed to sturdier morphologies being less fragile to wave action during the

cyclone (Baldock et al., 2014) and self-recruitment from surviving adult colonies (Graham et al., 2011). These genera may also have a competitive advantage against secondary cyclone impacts as they are relatively more tolerant to stress (Darling et al., 2013). The genus *Acropora* is the most abundant genus in the study region, so its recovery is crucial for the maintenance of the coral ecosystem. The ability of *Acropora* to rapidly colonise space following a disturbance through fragmentation or recruitment may explain the increase in the relative abundance of *Acropora* recruits after Cyclone Haruna (Pratchett et al., 2020). This is consistent with previous studies where *Acropora* has rapidly recovered in the aftermath of disturbance events, attributed to fast growth and high levels of recruitment (Sheppard et al., 2002; Linares et al., 2011).

4.5.4 Recovery and implications of cyclone impacts

The persistence of the coral community assemblage is dependent on the return interval and intensity of disturbance events (Pratchett et al., 2020). The reef community in southwest Madagascar has evolved with relatively frequent cyclones (Puotinen et al., 2020). Since 1913, there have been 15 cyclones recorded in the region, 13 of these have been category 1 on the Saffir-Simpson scale (Knapp et al., 2010). The remaining two cyclones were Cyclone Earnest (category 3) in 2005 and Cyclone Haruna. No other reports regarding the impact of cyclones on coral reefs in southwest Madagascar are available. However, we can assume the severity of damage caused by category 1 cyclones would be, in general, less than observed following Cyclone Haruna (Fabricius et al., 2008). It is predicted anthropogenic climate change will cause the global average intensity of tropical cyclones to increase (Knutson et al., 2020) and therefore the return interval between damaging cyclones to shorten (Puotinen et al., 2020). Predictions of changes to the size, frequency and spatial distribution of cyclones are more uncertain (Knutson et al., 2020) however, evidence suggests the poleward migration of the latitude at which cyclones reach maximum intensity is already occurring (Kossin et al., 2014). If this trend continues, tropical cyclones may become more prevalent in southwest Madagascar.

The high rates of replenishment of *Acropora* may be sufficient for the reef ecosystem to recover between cyclone impacts (Thompson and Dolman, 2010). However, mass

coral bleaching and mortality caused by marine heatwaves (MHWs) will likely be the leading control on the composition of reef communities (Loya et al., 2001) and lead to an increase in the relative abundance of thermally tolerant species (Woesik et al., 2011). Since the late 20th century, MHWs have increased in frequency, intensity and duration in the Mozambique Channel and southwest Madagascar has experienced the longest and most extreme MHWs in the region (Mawren et al., 2021). Under a high emission scenario (RCP 8.5), MHWs are predicted to become more intense and prolonged in the WIO (Jacobs et al., 2021). When the impact of tropical cyclones and MHWs are combined in a disturbance system of threats that also includes *Acanthaster* spp invasions (Bigot and Quod, 2000), coral diseases (Sheridan et al., 2014) and anthropogenic pressures, such as overfishing (Brenier et al., 2011; Gilchrist et al., 2020; Gough et al., 2020), it is likely the reef composition will change to be dominated by stress-tolerant coral taxa (Loya et al., 2001; Woesik et al., 2011).

A shift in the community composition to an assemblage dominated by massive and robust stress-tolerant genera has already been observed in areas of southwest Madagascar (Harris et al., 2010) and in other reef regions (Hughes, 1994; Fine et al., 2019). Dominance of less complex morphologies will alter the habitat availability and likely lead to a decline in the biodiversity and abundance of reef-associated organisms (Pratchett et al., 2008). Small-bodied and juvenile reef fish are particularly vulnerable to a decreased reef complexity (Richardson et al., 2017; Fontoura et al., 2020) they rely on the coral for refuge and nutrition (Gratwicke and Speight, 2005).

In Vezo small-scale fisheries, reef fish represent 30% to 50% of target fish species (Blue Ventures, unpublished data). Therefore, a change to reef fish populations may have implications for the food security and livelihoods of Vezo communities. While it is not possible to remove the threat of cyclone damage to corals, marine management measures can help reduce the likelihood of catastrophic regime shifts. For example, protecting a diversity of coral habitats from destructive fishing gear will provide an opportunity for a diversity in ecosystem responses (Nyström et al., 2008) and provide an insurance policy against losing ecosystem functions (van Nes and Scheffer, 2005). Where herbivorous fish are heavily exploited, removing fishing pressure can support the existence of diverse functional groups of herbivores and reduce the risk of a shift from coral to algal dominance after a disturbance event

(Graham et al., 2015). Within the Velondriake LMMA, no-take zones permanently closed to extractive activities have been found to have significantly higher fish biomass than fished sites (786 ± 247 kg/ha vs 247 ± 33 kg/ha; Gilchrist et al. 2020), indicating their potential role in coral recovery.

4.5.5 Opportunities for local monitoring and citizen science

In the present study, we used long-term monitoring data collected by trained field staff (nationals and international) and international citizen science volunteers to assess the impact of Cyclone Haruna. This programme was not designed to monitor disturbance-related responses in coral health, and therefore variability in the spatial distribution and sample replication of surveys inhibited deeper investigation into the impact of Cyclone Haruna on reefs. However, despite challenges and limitations in data analysis, in remote and data-scarce regions, using the data that *is* available is critical to support local reef health and strengthen regional knowledge of ecological and societal outcomes for coral reefs and dependent communities. Engaging local stakeholders in reef monitoring is critical to foster public support for coral reef conservation and local ownership of management efforts (Aswani et al., 2015). Monitoring programmes must be accompanied by skills training and sustainable financing (Hattam et al., 2020). In locations with economic constraints, citizen science provides an opportunity to support robust large-scale and long-term monitoring (Chandler et al., 2017). Monitoring approaches should be designed to address localised threats to coral health and social-ecological dynamics yet guided by global best practices (e.g. Global Coral Reef Monitoring Network; Hill and Wilkinson, 2004) to allow for the aggregation of data at a global level (Freiwald et al., 2018). As disturbance regimes increase on coral reefs, monitoring coral reef status and trends will provide critical data which can be used to inform local marine management and national and international obligations to support reef health (Obura et al., 2019).

4.6 Conclusion

This paper presents the first published record of the impact of a tropical cyclone on coral reefs in Madagascar. Disturbances, such as cyclones, have major impacts on the structure and functioning of coral reef communities. The frequency of severe

disturbances to coral communities is predicted to increase as climate change progresses, with the potential for severe consequences for those who rely on reef-associated marine resources for their livelihoods. Cyclone Haruna had an immediate impact on the hard coral cover and community assemblage on the coral reefs located in the Velondriake LMMA. Following the cyclone, the morphological composition shifted from being dominated by branching genera to massive and encrusting genera. Two years after the cyclone, hard coral cover increased, and the density of coral recruits increased to above pre-cyclone levels indicating the potential for recovery of the coral population. Our results contribute to extending the geographic evidence of cyclone impacts on reefs and increase knowledge of cyclone impacts on reefs in the WIO. Understanding coral community responses to disturbances is important to inform and support effective reef and resource management actions.

For the Velondriake LMMA, we recommend ensuring that no-take zones are in place and that these areas protect a range of habitats with distinctive coral assemblages. Velondriake currently has a network of five coral reef no-take zones, so we recommend further research exploring whether these NTZs protect a range of coral assemblages.

As climate-driven impacts on reefs increase in frequency and severity, a more geographically equitable picture of these impacts is needed. Often, areas that are data deficient are also places where coastal communities have a high dependence on seafood and coral reefs for nutrition, and where lives are most closely entangled with the sea. Without a detailed picture of cyclone impacts and recovery, we cannot tailor management recommendations to account for local, or even regional ecology and oceanography, ultimately further threatening both unique coral ecosystems, and the lives and livelihoods of the people who depend on them.

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4.7 Further Insights

4.7.1 Marine Resource Management and Natural Hazards

In communities with high dependence on marine resources, the ecological impacts of cyclones or other natural hazards have cascading social impacts related to disturbances in the coastal ecosystem (Thomas et al., 2019). However, knowledge gaps remain on the coupling of social and ecological impacts with respect to natural hazards and their implications for decision-making (Thiault et al., 2018; Depietri, 2020). Social data regarding the impact of Cyclone Haruna in Velondriake was not available. Likewise, little information is available about the impacts of cyclones on coastal communities in Madagascar. Nevertheless, to put this study within the broader context of the overall thesis, specifically addressing potential social-ecological links and implications for co-management, I draw on previous literature to present a discussion of these topics.

Tropical cyclones and associated floods can result in the loss of human life and large economic losses (Doocy et al., 2013). Specific to fishing communities, severe implications on food security and income can arise from direct impact of the cyclones on the marine resources (Thomas et al., 2019). Indirect impacts can also arise from the destruction of infrastructure and gear e.g. damage to boats, nets and landing sites (Kundu and Santhanam, 2021). Longer term, decreased reef rugosity (as a result of cyclone damage) may increase wave exposure and decrease availability of reef resources (Harmelin-Vivien, 1994). Mitigating the societal impact of tropical cyclones will involve lowering the vulnerability of coastal communities to disturbances by strengthening resilience and adaptive capacity (Depietri, 2020). Community-based fisheries management is increasingly recognised as a potential pathway to improved adaptive capacity in the face of climate disturbances (Ferro-Azcona et al., 2019; D'agata et al., 2020; Pike et al., 2022), therefore suggesting such strategies have relevance for reducing cyclone risk.

Indeed, there are several ways community-based marine management has been found to strengthen post-disaster recovery of fishing communities from natural hazards. First, social capital related to community-based management has been associated with an increased capacity to deal with shock. For example, social

networks and collaboration related to fisheries management were associated with recovery following tsunamis that impacted fishing communities in Chile (Marin et al., 2015) and Sri Lanka (De Silva and Yamao, 2007).

Second, community-based management, and in particular co-management, is increasingly associated with developing alternative livelihood projects in fishing communities (Rocliffe et al., 2014; Gardner et al., 2020). Diverse livelihood portfolios have been shown to increase resilience to shocks (Eriksson et al., 2017). However, this is dependent on what these livelihoods are (Mills et al., 2011). Activities that rely on the same productive environment will have increased exposure to risk. For example, the infrastructure for seaweed and sea cucumber aquaculture within the Velondriake LMMA may both be at risk of damage in the face of strong wind and wave action during a cyclone.

Finally, strong fisheries management and organisation can support adaptive policies in the face of significant disturbances to the social-ecological system. For example, as demonstrated in this chapter, cyclone damage is spatially heterogeneous. Therefore, adapting management policies to prevent further damage in highly damaged areas following a cyclone (e.g. through restrictions on destructive gear or temporary fishery closures) could help maintain ecological functioning and support coral recovery (Darling et al., 2019). To achieve this, it is imperative that the management unit be of a sufficiently large scale to encompass a variety of coral habitats (Nolan et al., 2021). On the other hand, adaptive policies to increase fisheries access could provide a 'safety net' to increase resource availability to support communities' food security and income in times of crisis. For example, Eriksson et al. (2017) found that incorporating a flexible management approach that facilitated opening no-take zones following a natural disaster in Vanuatu increased food access and income during a time of emergency. Spatial closures were re-established once the crisis had passed, improving capacity in meeting immediate recovery needs while not resulting in long-term unsustainable fishing patterns. Flexible fishery management approaches may also generate greater levels of legitimacy and societal support for restrictive interventions (Edmondson and Fanning, 2022).

Considering the increasing likelihood of severe cyclones impacting coastal communities in Madagascar, evidence suggests that community-based management arrangements provide a promising opportunity to support the adaptive capacity of coastal communities that align with sustainable fisheries management efforts. Figure 4.4 outlines how the coral reef ecosystem interacts with the social system to shape risk in the face of cyclones and how it could be improved through community-based management. This extends beyond Madagascar and holds relevance for other communities dependent on reef ecosystems.

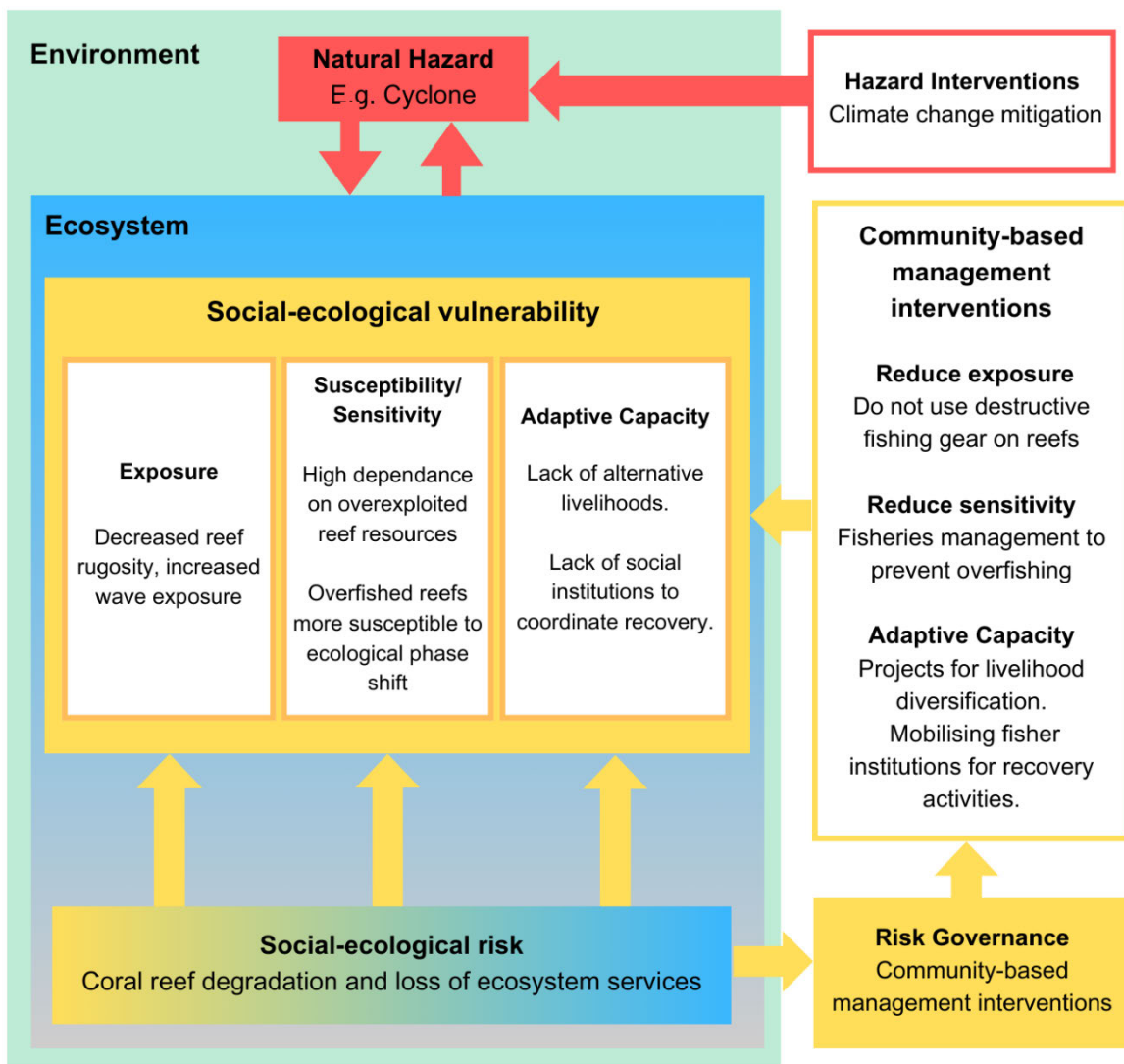


Figure 4.4 Framework representing the elements and interactions that shape social-ecological vulnerability and risk of exposed systems to natural hazards in the context of risk governance. Using the example of a tropical cyclone and community-based management in reef-dependent communities. Adapted from Birkmann et al., (2013) and Depietri (2020)

4.8 Chapter Afterword

This chapter provides detailed empirical evidence of the ecological disturbance and response of coral reefs in southwest Madagascar caused by a tropical cyclone. We found the damage was spatially heterogeneous throughout the study region and that the coral reef sites showed positive signs of recovery in the two years following the cyclone. However, the increased frequency of destructive cyclones in combination with widespread coral bleaching caused by marine heatwaves will likely cause a shift in the coral assemblage to be dominated by resilient species. Fisheries management will not directly increase the coral reef resilience to cyclone damage, but it may be a key factor in reducing the likelihood of ecological phase shifts by supporting herbivory and decreasing the likelihood of reef damage via destructive gear. Moreover, evidence from other regions indicates that community-based management can have additional social-ecological benefits when confronting natural hazards. For example, through enhanced social capital, the diversification of livelihood and the framework for adaptable management, ultimately facilitating improved access to food and income during crises. Thus, adding further imperative to enhance local management practices and align them with national and international policies as coastal communities increasingly face threats from natural hazards. These findings contribute to Research Objective 1 of this thesis.

4.9 Reference List

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Chapter 5: Adaptive capacity of small-scale fishing communities in the face of diverse disturbances



A Vezo fisher returning from gleaning during low tide with a pirogue full of with *buzike* (sea urchin). Image: ACarter

5 Adaptive capacity of small-scale fishing communities in the face of diverse disturbances

This chapter is being developed into a manuscript to be submitted to the interdisciplinary journal *npj Ocean Sustainability*.

5.1 Chapter Foreword

This research chapter investigates the dynamics of adaptive capacity in the Velondriake LMMA. The idea for the chapter was first conceived amidst the COVID-19 travel ban in early 2020. Faced with uncertainty about my ability to visit Madagascar, I formulated the initial research question using available data from Velondriake. Leveraging a socioeconomic survey conducted by Blue Ventures in 2016, I identified it as an excellent opportunity to explore the dynamics of adaptive capacity within the context of co-management setting—a knowledge gap I had identified within the existing literature. Recognizing further opportunity to include temporal analysis in the study, I helped facilitate the same socioeconomic survey to be repeated in 2021. I was still unable to be physically present, however, in collaboration with Blue Ventures, I provided remote support for the survey organisation.

This research chapter contributes to Research Objective 2 by increasing understanding of the dynamics of adaptive capacity reef-dependent fishing communities.

5.2 Introduction

Throughout the coastal tropics, coastal communities have high dependence on small-scale fisheries for their food security and livelihoods (Cohen et al., 2019). This dependence is particularly pronounced in developing nations, where fish can provide up to 90% of animal protein (Bell et al., 2009; Barnes-Mauthe et al., 2013) and few economic opportunities may exist outside small-scale fishing (FAO, 2020). Such high levels of dependence mean communities are highly vulnerable to climate stressors on the marine ecosystem (Barange et al., 2014; Lam et al., 2020) and

socioeconomic disturbances (Crona et al., 2015; Bassett et al., 2021, 19) that disrupt the small-scale fisheries sectors.

Climate stressors such as increased sea surface temperatures and more frequent extreme events (e.g., cyclones and marine heatwaves) are expected to cause irreversible changes to marine ecosystems (Cheung et al., 2010; Cinner et al., 2022). When compounded with other human-induced pressures (e.g. overfishing, pollution, land-use change) it is likely the ecosystem services provided by tropical marine ecosystems will be significantly altered (Eddy et al., 2021). Stressed ecosystems are likely to be less productive, therefore undermining the livelihoods and food security of small-scale fishing communities (Frawley et al., 2019; Knight et al., 2020; Mangubhai et al., 2021).

Concurrent with climate stressors, coastal communities are vulnerable to global socioeconomic drivers and shocks. While traditionally focused on subsistence and local trade, small-scale fisheries' supply chains are increasingly nested in global markets (Cohen et al., 2019). This has increased interdependencies with external market chains and networks and coastal communities' exposure to socioeconomic disturbances (Knight et al., 2020). A recent example of this was the socioeconomic repercussions of the COVID-19 pandemic. The pandemic's socioeconomic effects were particularly pronounced among populations and sectors already facing marginalization (McLennan, 2021). Small-scale fishers, traders, and processors emerged as highly vulnerable to the pandemic's impacts (Bennett et al., 2020). In export-orientated small-scale fisheries, COVID-19 disruptions caused supply chain breakdown, reduced demand and a collapse in prices. For small-scale fishers situated in developing countries, who are recognized as among the most economically vulnerable groups globally (Béné and Friend, 2011), this led to direct economic and food security implications (Bennett et al., 2020; Ferrer et al., 2021; Mangubhai et al., 2021).

In the face of threats from climate change and socioeconomic shocks, the extent to which coastal communities can effectively respond is largely influenced by their adaptive capacity. Adaptive capacity describes people's ability to modify their exposure to risk, absorb and recover from loss, and exploit new opportunities (Adger

and Vincent, 2005). For example, those with high adaptive capacity may be better equipped to convert social, economic and natural resources into successful adaptation outcomes in the face of change.

Consequently, enhancing people's adaptive capacity is a key element of management and policy responses to a broad spectrum of uncertain external threats to small-scale fishing communities. Evaluating adaptive capacity relies upon measuring social characteristics often grouped in categories and sub-categories (i.e. “domains” and “indicators”). Change in adaptive capacity is likely to occur through different drivers that could positively or negatively impact the adaptation process within a domain. Drivers external to the community (e.g. government policies, NGO activities, market forces and private investment) will have feedback with internal drivers which influence outcomes related to adaptation (Figure 5.1; Bartelet et al., 2022). Conferring adaptive capacity for diverse disturbances is complex, as approaches to building adaptive capacity can interact antagonistically (Thiault et al., 2018). For example, the type (e.g. climate change vs socioeconomic shock) and timescale (e.g. chronic vs acute) of the stressor may require different adaptive responses (Adger and Vincent, 2005). Therefore, managing for multiple stressors requires consideration of ‘generic’ adaptive capacity which can have applicability to a multitude of stressors (Thiault et al., 2018; Green et al., 2021).

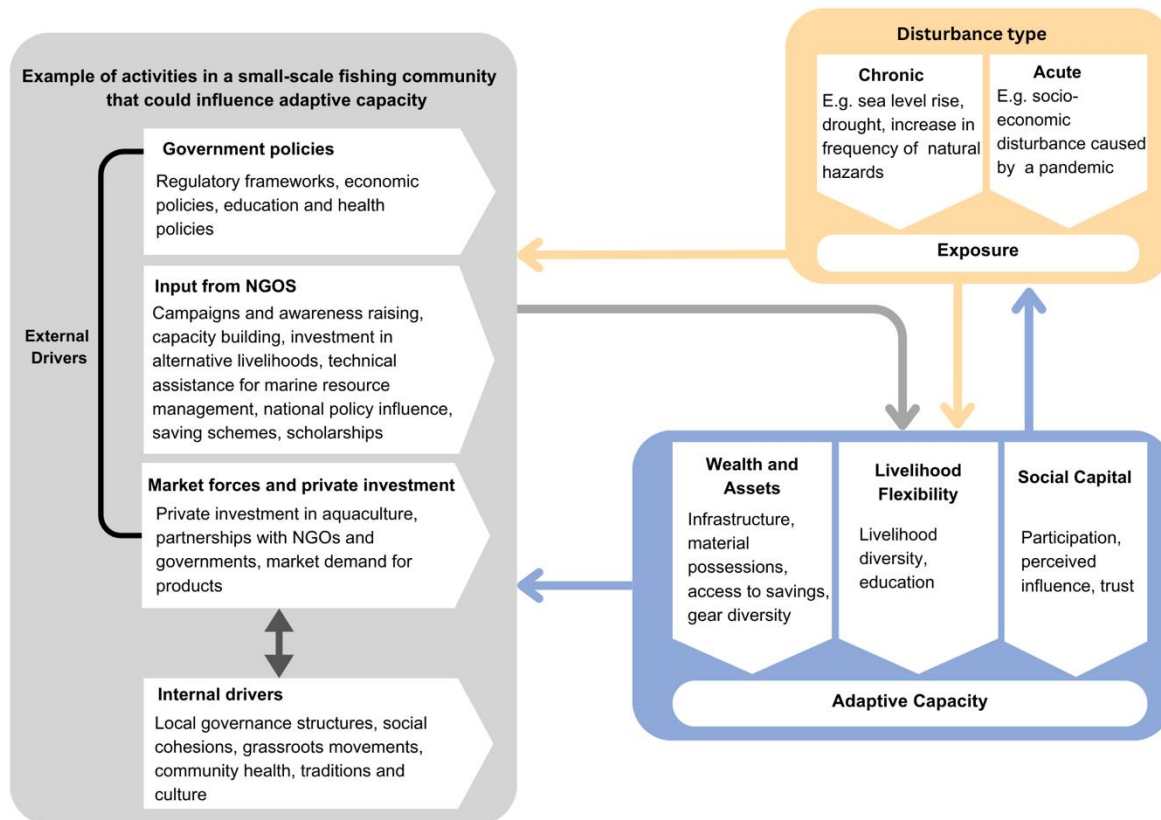


Figure 5.1 Conceptual framework to demonstrate the interdependent relationships and consequential linkages between exposure to chronic and acute disturbance events, external and internal drivers of adaptive capacity and adaptive capacity domains. The type of disturbance is a mediating factor in the relevance of adaptation outcomes.

Despite a substantial body of research examining adaptive capacity within SSF communities (e.g. Fazey et al., 2007; Cinner et al., 2015, 2018; D’agata et al., 2020), several knowledge gaps persist which may limit its utility to decision-makers. First, most adaptive capacity studies are undertaken at household or community level however this does not fully capture the inequities of adaptive capacity between social groups, for example, based on age or gender. Second, adaptive capacity does not remain static and will change over time, influenced by external factors such as the biophysical, political and socioeconomic context. However, there is a lack of longitudinal studies in adaptive capacity literature (Cinner et al., 2015; Vallury et al., 2022). Third, evaluating domains and indicators of adaptive capacity often relies on hypothetical predictions, without empirical testing of the indicators’ relationship to actual responses of households and communities (Green et al., 2021), thereby

undermining confidence in the reliability of adaptive capacity approaches in shaping policy decisions.

In this study, I address these three knowledge gaps using the case study of southwest Madagascar. Southwest Madagascar presents an important opportunity for investigating adaptive capacity for several reasons. First, Madagascar has one of the highest poverty rates in the world (World Bank, 2023) and the southwest is one of the poorest regions (Silva-Leander, 2020). The region is home to the Vezo, traditional fishers whose livelihood and culture have been strongly tied to the ocean for millennia (Astuti, 1995). In this region, seafood provides 99% of protein, and 87% of the adult population derives their livelihoods from small-scale fishing (Barnes-Mauthe et al., 2013). An arid climate limits land-based employment or food production opportunities, upholding a high reliance on fisheries (Harris, 2007; Barnes-Mauthe et al., 2013)

Second, the degradation of the marine ecosystem in Madagascar is already affecting the availability of marine resources, thereby impacting food security and livelihoods (Bruggemann et al., 2012). An increase in the number of fishers, improved gear technology and the international seafood export market have all been identified as drivers of unsustainable fishing and studies on fish biomass and catch trends in the region indicate that overfishing is occurring (Gilchrist et al., 2020; Gough et al., 2020, 2022). Concurrently, the marine ecosystems are threatened by the impact of climate change through marine heatwaves (Nadon et al., 2008; Gudka et al., 2018) and increasing frequency of intense cyclones causing degradation of the coral reef ecosystem and potential decline in reef productivity (Cheal et al., 2017; Carter et al., 2022). Furthermore, decreasing rainfall is diminishing the limited opportunities for agriculture in the region and driving migration of inland communities to the coast. Thus, owing to high levels of reliance on the degrading marine ecosystem, adaptation is a current necessity rather than a distant possibility.

Third, the COVID-19 pandemic had severe socioeconomic consequences for fishing communities in southwest Madagascar (Brayne, 2020). COVID-19 related restrictions substantially curtailed national travel from March 2020. A large proportion of trade in southwest Madagascar operates on a bidirectional trade route on poorly

constructed roads and therefore a travel ban significantly impacted trade and food access. The limitation on transport and disruption to agriculture caused an increase in the price of important diet staples such as rice. This had a knock-on effect on food access within Vezo fishing communities who do not cultivate rice themselves. Price increases in staple food products were combined with a decrease in the buying price and demand for fish products from international buyers, reducing fishing income (Leeney et al., 2022). By 2021, transport and trade had largely returned to pre-COVID conditions, although staple food prices on the southwest coast remained higher (A. Carter, Pers Obsv). Owing to the limited availability of COVID-19 testing, relatively little is known about the health impacts of COVID-19 in southwest Madagascar. Anecdotal reports from local healthcare services indicate COVID-19 did not arrive in the region until April 2021 when there were 6 deaths and 200 suspected cases over a 2 week period (Scudellari, 2021). COVID-19 provides an unwelcome yet unique test case to investigate the impacts of an acute socioeconomic disturbance on small-scale fishing communities that can be used as a proxy for other system-pervasive shocks.

Finally, southwest Madagascar is home to several locally managed marine areas operating in a co-management framework. These management regimes have diverse objectives, including activities to conserve and restore biodiversity and fisheries and support sustainable livelihoods and food security of local resource users (Roccliffe et al., 2014; Gardner et al., 2020). These frameworks have also supported the collection of longitudinal data in social, fisheries, and ecological contexts. It has been stated that marine governance models have the potential to confer adaptive capacity in coastal communities, however, this aspect remains largely unexplored. Although my analysis will not empirically test the impact of co-management on adaptive capacity, it provides the opportunity to contextualise findings within co-management interventions. This approach aims to offer tangible insights for local management in communities with marine resource dependence across the tropics.

Herein, the objective of this study was to investigate social and temporal dynamics of adaptive capacity and the relationships between adaptive capacity and diverse disturbances in coastal communities in southwest Madagascar. To do this, I ask

three questions (1) how adaptive capacity varies over time, (2) how adaptive capacity varies between social groups (gender, age, village habitat type) and (3) what is the relationship between adaptive capacity indicators and impacts and responses to chronic and acute disturbance events.

To investigate adaptive capacity, I use a repeated social survey collected in eleven coastal villages in 2016 and 2021. I examine three domains of adaptive capacity: (1) assets, the resources people can access during times of change, (2) social capital, how social relationships, networks and trust shape outcomes and (3) flexibility, opportunities for switching between adaptation strategies (Cinner et al., 2018). I consider the ongoing impact of climate and weather events (cyclones, sea-level rise, drought, and floods) as a chronic climate stressor, characterised by the cumulative impact of climate events lacking a specific end date (hereinafter referred to as “climate impacts”). I consider the socioeconomic disturbance of COVID-19 as an acute socioeconomic stressor, representing a time-limited disturbance.

5.3 Methods

5.3.1 Study Region

This study was located in the Velondriake Locally Managed Marine Area (LMMA) in southwest Madagascar. The Velondriake LMMA stretches along 40km of coastline and currently incorporates 35 coastal villages with a population of around 8000. The coastline is characterized by areas of seagrass and mangroves with fringing reefs, patch reefs and a barrier reef located around 2 km from shore (Figure 5.2). Villages in Velondriake are in a variety of habitat types which are relevant to this study as they may influence the socioeconomic circumstances of the village. Thereby, the villages are divided into island villages, coastal villages and mangrove villages (Barnes-Mauthe et al., 2013). Coastal villages can be characterized by being located on the open coastline usually next to an accessible beach, mangrove villages have significant mangrove stands between them and the shore and island villages are located on islands in the lagoon between the mainland and the barrier reef. Comanagement first began in the region in 2004 when the NGO Blue Ventures supported trial periodic fishery closures for octopus. Over the past two decades, the LMMA has incorporated a growing number of management practices including

numerous periodic fisheries closures (primarily for octopus) located on reef flats, five permanent coral reef reserves and two mangrove reserves. Blue Ventures has also extended its support to the communities in other ways. They have collaborated with national and international partners to support sea cucumber and seaweed aquaculture. Additionally, they have established a community health program and educational programs, such as an after-school environmental education youth club and a scholarship program, aimed at assisting students in attending the university in the nearest city, Toliara.

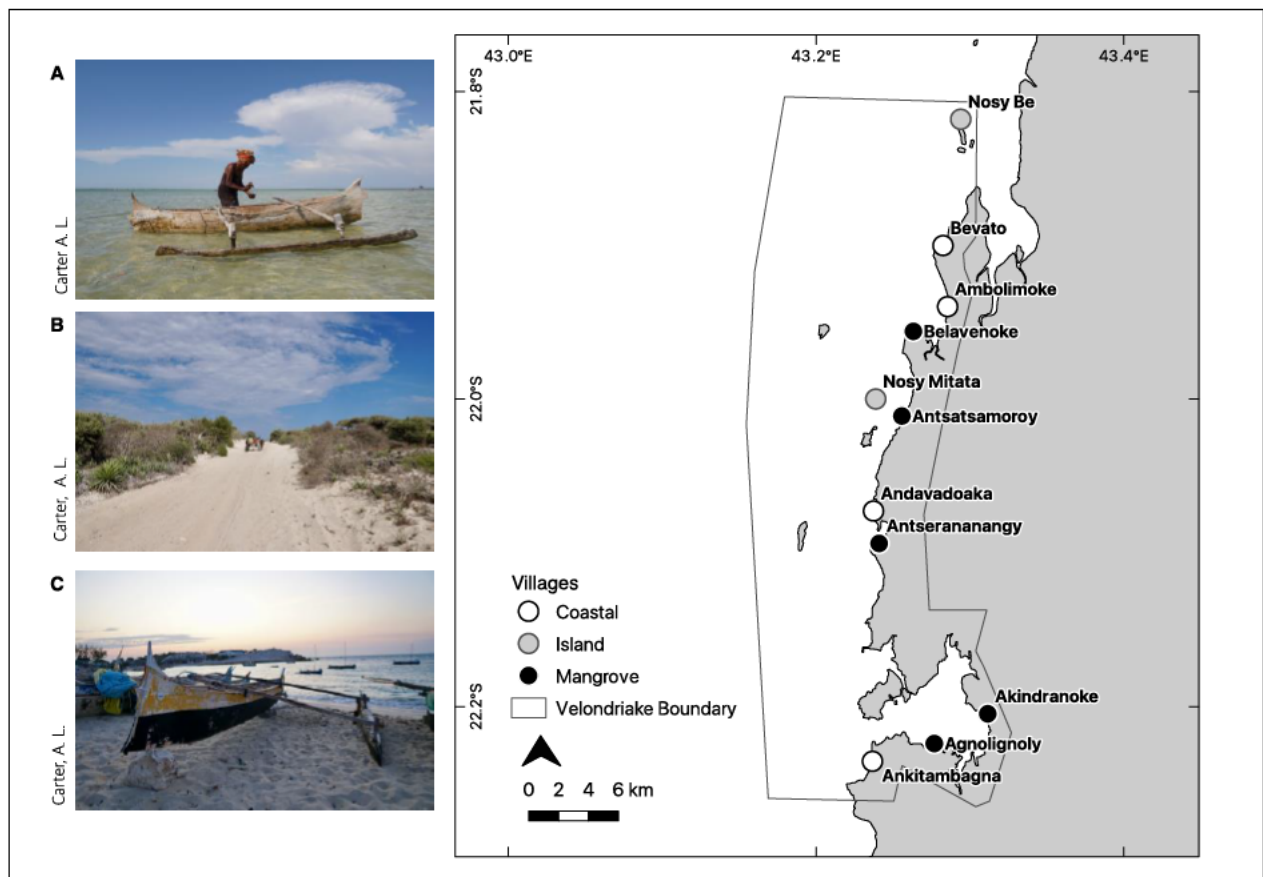


Figure 5.2. Map and photos of the study region. (A) Fisherwomen breaking open sea urchins after gleaning at low tide, (B) the main road that runs north to south (C) traditional wooden dug-out canoe used for fishing activities

5.3.2 Sampling design

This study used data from household surveys undertaken in 11 villages in 2016 and again in 2021 collected as part of Blue Ventures' socioeconomic monitoring in the region. The population was estimated from a population count in each village prior to the surveys. In 2016, the villages were selected following the approach taken by

Barnes-Mauthe et al., (2013) where villages were characterized by geographic location (north, central and south) and setting/habitat type (coastal, island, mangrove). To select which villages were to be surveyed the probability proportional to size (PPS) method was employed, with the selection based on the population size of each village. PPS is a sampling technique in which the likelihood of selecting a specific sampling unit (a village) is proportional to a known common variable (population size). For this analysis, I included data from 11 of the villages visited in both 2016 and 2021. In 2016, 238 respondents were interviewed, representing 14% of the adult population in the 11 villages at that time. In 2021, 336 respondents were interviewed, 12% of the adult population in the same 11 villages. The number of respondents in each age/sex strata was based on the average strata proportions of the whole population calculated in 2016. The survey had a combination of closed, binary (yes/no), multiple choice and Likert scale questions. Surveys were undertaken by trained Malagasy field staff in Vezo dialect.

5.3.3 Social Data and Analysis

Based on questions that were asked in the 2016 and 2021 Blue Ventures socioeconomic survey, I generated nine indicators of adaptive capacity based on a list of commonly used indicators described by Siders et al. (2019) and other established research in the field (Table 5.1). In 2021, questions were also added about the impact and recovery from climate events and the COVID-19 pandemic (Table 5.2). At the time of the 2021 survey from September to December 2021, national COVID-19 restrictions in Madagascar had lifted but international travel was still limited.

I conducted three types of analyses. First, I examined whether each adaptive capacity indicator changed over time in the 11 villages from 2016 to 2021. For this temporal analysis, a pseudo-panel approach was used. This consists of independently drawn cross-sections of a population sampled at two different time points, typically comparing means or medians between time periods. Pseudo-panel data contrasts with panel data which follows individuals over time (Stockemer et al., 2019). Second, I examined if in 2021 there were statistical differences in adaptive capacity indicators between groups based on: gender, age and village habitat type. Finally, I investigated the relationship between adaptive capacity indicators and

reported impacts and recovery to chronic (climate events) and acute (COVID-19) disturbance events.

I conducted analysis to investigate the influence of each grouping variable on the adaptive capacity indicator, with the adaptive capacity indicator as the response variable (Cinner et al., 2015). I fitted linear mixed models for continuous data, generalized linear mixed models (binomial family) with a logit link for binary response variables, generalized linear mixed models (Poisson and negative binomial) for count and duration and multinomial logistic mixed models with a cumulative logit link for the ordinal response variables. I included village as a random effect in all models except when the general linear mixed model converged on a singular fit due to a near-zero variance. In these cases, I ran a general linear model with no random effects. I assessed the significance of the effect of the predictor variable on the adaptive capacity indicator using a Likelihood Ratio Test (LRT) between the full model and the null model and assessed the change in the Akaike Information Criterion (AIC). A model was considered significant when the LRT had a p-value < 0.05. A reduction in the Akaike Information Criterion (AIC) by more than 5 units from a null model to a more complex model is considered indicative of an improved model fit. At significance level $p < 0.05$ for the LRT, there are instances where the change in AIC did not exceed -5. This indicates the model improvement may not sufficiently outweigh the added complexity of introducing the explanatory factor. Nevertheless, recognizing the exploratory nature of this analysis and the fact even marginal improvements in model fit could offer valuable insights for guiding conservation decision-making (Field et al., 2004; Fidler et al., 2006; de Bie et al., 2018), I include these in my discussion. Spider plots are used to visualise relationships between adaptive capacity indicators and predictor variables.

I conducted additional analysis using combined models where each grouping variable was the dependent variable and the adaptive capacity indicators were independent variables in a single model. The significance of each predictor, the Akaike Information Criterion (AIC) and the LRT were investigated for each model (See Appendix 2.3 for description and results of an alternative modelling approach). While both modelling approaches yielded similar results, certain grouping variables produced more consistent outcomes than others. Regression assumes uniformity in

independent and dependent variables (Ranganathan et al., 2017). Thus, considering several predictors simultaneously introduces complexity (non-linearity, interaction), potentially obscuring relationships that are captured in individual models (Harrell, 2015). Given that my research questions focused on interactions between adaptive capacity indicators and grouping variables rather than the interactions between adaptive capacity indicators, I focus on output of the first modelling approach in my discussion.

Table 5.1 List of domains and indicators of adaptive capacity operationalized in this study

	Indicator	Description	Measure	Type of data	Relevance for adaptive capacity	References
Wealth and Assets	Community infrastructure (2021 only)	The number of community-scale infrastructure items present: primary school, secondary school, well, public transportation, access by road, freezer, internet network, homestay, grid electricity, community hospital, community health centre, community health worker, community dentist	Number of items (0-13)	Continuous (count)	The presence of infrastructure items can directly influence how well a community can adapt to and navigate unforeseen circumstances, ensuring the continuity of essential services	Pollnac, 1998; Cinner et al., 2015; Mozumder et al., 2018
	Material style of life (MSL)	Whether the respondents had 7 material possessions including vehicle, table and chairs, pirogue, radio, TV, bed and mobile phone and is used as an indicator of relative wealth	First axis of the principal components analysis (Further details in Appendix 2.1)	Continuous	Serves as proxy for wealth which can support adoption of adaptation strategies in times of need	McLeod et al., 2012; Cinner et al., 2015; McClanahan et al., 2008
	Access to savings	Whether the respondent has access to savings	Yes-No	Binary	Savings can be used to support adaptation of adaptation strategies in times of need	Cinner et al., 2015

	Gear diversity	The number of different types of fishing gear owned by the respondent from a list of 11 options.	Number of types of fishing gear (0-11)	Continuous (count)	Different gear types can support fishers moving to new environment and/or new species if their current methods become unproductive due to change	McClanahan et al., 2008a; Cinner et al., 2013
Social Capital	Natural Resource Management (NRM) Participation	Whether the respondent attended natural resource management meetings	No; sometimes; rarely; always	Ordinal	Participation can support access to information and relations to external agencies to support informed decisions and access resources in times of need.	Pretty, 2003; McClanahan et al., 2008a; Cinner et al., 2015
	Natural Resource Management (NRM) Influence	Whether the respondent felt they could influence decisions at natural resource management meetings	Yes-No	Binary	Perceived influence can encourage proactive decision-making, shape risk perception and promote learning and innovation in the face of uncertainty.	D'agata et al., 2022
	Trust (2021 only)	Whether the respondent trusted: people from own village, people from other villages, Velondriake association, local government, and Blue Ventures	An average of Likert scale response to levels of trust	Continuous	Trust supports effective communication and collective action in time of uncertainty	Cinner et al., 2015

Livelihood Flexibility	Livelihood diversity	The number of alternative livelihood options that were not in the category of fishing	Number of livelihoods (up to 3 options)	Ordinal	Can provide alternative income strategies when facing poor ecological conditions or socioeconomic instability	Allison and Ellis, 2001; McClanahan et al., 2008a; Cinner et al., 2015
	Education	Number of years respondent spent in education	Number of years (0-13)	Continuous (duration)	Education enhances knowledge, resource allocation efficiency, and capacity to plan for the future including proactive strategies to mitigate risk from change.	Fazey et al., 2007; Islam et al., 2014

Table 5.2. Example of survey questions about climate events and COVID-19

Disturbance	Example Survey Question	Response Options
Climate or weather events (chronic)	To what extent have climate disturbances (e.g., cyclones, severe storms, drought) affected your livelihood?	Many negative impacts; some negative impacts; few negative impacts; no negative impact; do not know
COVID-19 (acute)	To what extent did the COVID-19 pandemic affect the weekly income of you and your family?	Increased; no change; decreased; do not know
	To what extent did the COVID-19 pandemic affect access to food for you and your family?	Increased; no change; decreased; do not know
	If your weekly income was affected by COVID-19, how is it now?	Increased; same; decreased (compared to before COVID-19)
	If your food access was affected by COVID-19, how is it now?	Increased; same; decreased (compared to before COVID-19)

5.4 Results

5.4.1 Response and Recovery to Disturbance Events

Nearly all respondents indicated that the impacts of the COVID-19 pandemic had decreased their income (97%) and a majority indicated that it decreased their access to food (78%). At the time of the surveys (between September and December 2021), 68% of respondents reported that their income was less compared to before COVID-19, 15% reported it was the same and 15% reported it was more. Most respondents (60%) reported that their access to food was lower than pre-pandemic conditions, 23% reported it was more and 16% reported it was the same. When asked to what extent climate or weather disturbances have affected their livelihood, 49% of respondents reported many negative impacts, 32% reported some negative impacts, 15% reported few and 3% of respondents reported none.

5.4.2 Adaptive Capacity Indicators

Overall, I found certain indicators of adaptive capacity to be significantly differentiated between social groups, dynamic over time and be significantly related to perceived negative consequences of chronic climate impacts and the acute socioeconomic disturbance caused by COVID-19 (Figures 5.3 to 5.5). To present an overview of key findings, I structure my results by adaptive capacity domain as outlined in Table 5. Non-scaled values for the adaptive capacity indicators are in Appendix 2.2.

5.4.3 Wealth and Assets

Indicators in the wealth and assets domain include savings, MSL, gear diversity and community infrastructure. Savings had a significant association with age, with a higher proportion of adults and young adults reporting access to savings compared to the senior age group (58% and 49% vs. 31%, respectively; Appendix 2.2). Additionally, a significant non-linear association emerged between savings and recovery from COVID-19 (Figure 5.4). Individuals with savings were more likely to report changes in access to food and income since the COVID-19 pandemic, while those without savings were more likely to report access returning to the same level. MSL did not show a significant association with social groups or a trend over time. However, a significant association was identified between perceived climate impacts and MSL, with those individuals with the lowest MSL most likely to report the most climate impacts.

The only wealth and assets indicator to show a temporal trend between 2016 and 2021 was gear diversity, which decreased among men (Figure 5.4). Gear diversity was also significantly associated with recovery of income following COVID-19 (Figure 5.5). The only grouping variable that community infrastructure is significantly associated with is village habitat. Coastal villages had the most infrastructure items (8.84 ± 3.70), followed by mangrove villages (5.16 ± 2.52), and island villages had the fewest (1.92 ± 0.28).

5.4.4 Social capital

Indicators in the social capital domain include NRM participation, NRM influence and trust. NRM participation and NRM influence were significantly different between age and gender, with men and individuals in the adult and senior age groups reporting higher levels of involvement and greater influence on management decisions (Figure 5.3). NRM participation and NRM influence had a non-linear association with perceived impact of climate events. Respondents with the highest scores in both indicators reported either no negative impacts or many negative impacts (Figure 5.5). Additionally, a significant association was found between NRM participation and food access following COVID-19 (Figure 5.5). There was no change in the indicators of social capital between 2016 and 2021.

5.4.5 Flexibility

Indicators in the flexibility domain include livelihood diversity and education. Livelihood diversity was significantly associated with gender and demonstrated a significant temporal trend for both men and women, with values increasing from a mean of 0.608 (± 0.728) to 1.25 (± 1.05) for women and from 0.442 (± 0.626) to 0.798 (± 0.899) for men (Figure 5.4). Residents of island villages reported the lowest livelihood diversity 0.292 (± 2.26), compared to 0.734 (± 3.60) and 0.841 (± 3.60) in mangrove and coastal villages, respectively (Figure 5.3). Village habitat type had significant association education with respondents from island villages reporting 1.83 (± 3.23) years in education compared to mangrove and coastal villages (Mangrove: 3.17 (± 3.23), Coastal: 4.12 (± 3.60); Figure 5.3). Education was not significantly associated with any other variables. In 2021, the average number of years in education for men was 3.31 (± 3.15) and for women 3.49 (± 3.23).

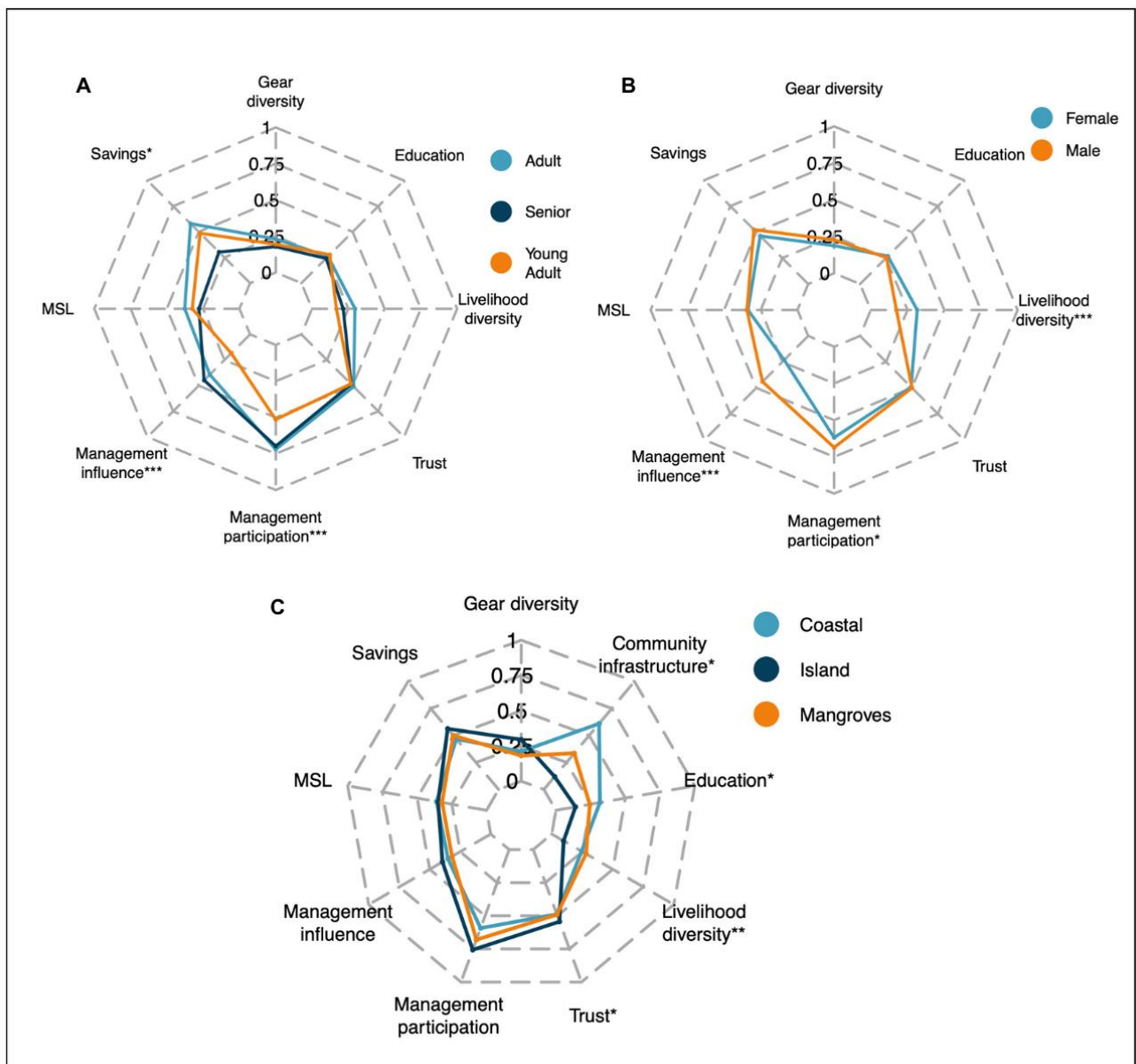


Figure 5.3 Variations in adaptive capacity among segments of fishing communities in southwest Madagascar including (A) age, (B) gender and (C) village habitat. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$. MSL, material style of life.

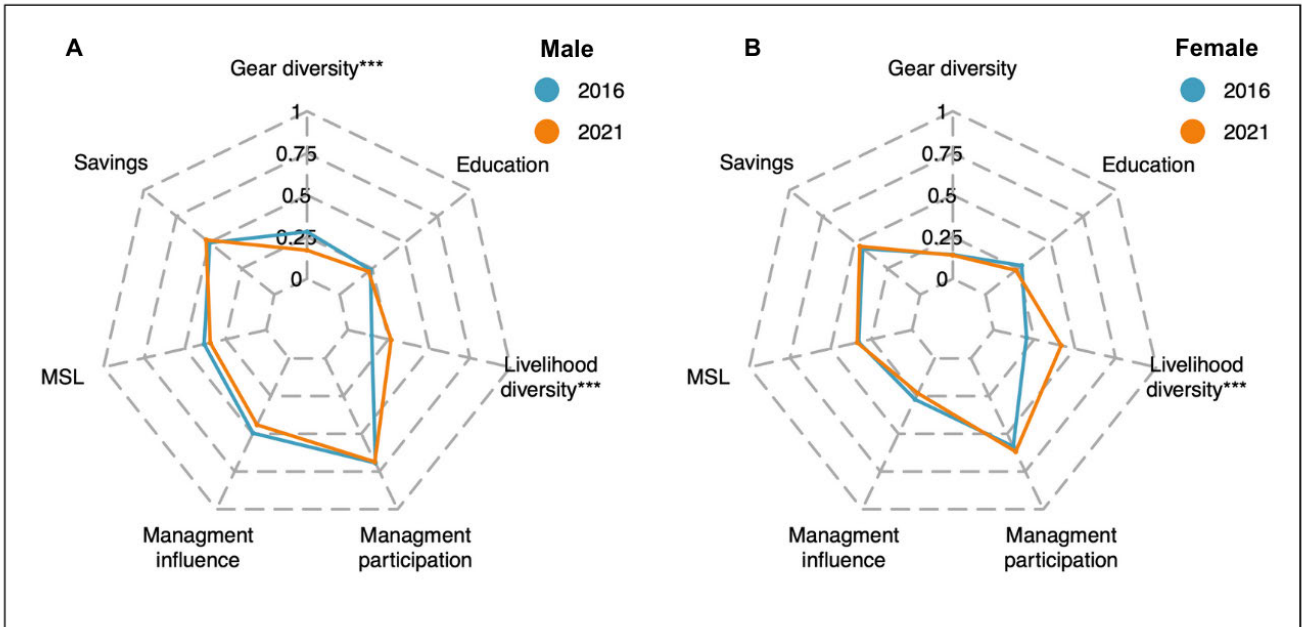


Figure 5.4. Change in adaptive capacity indicators over time for (A) men and (b) women in coastal fishing communities in Madagascar. *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$. MSL, material style of life.

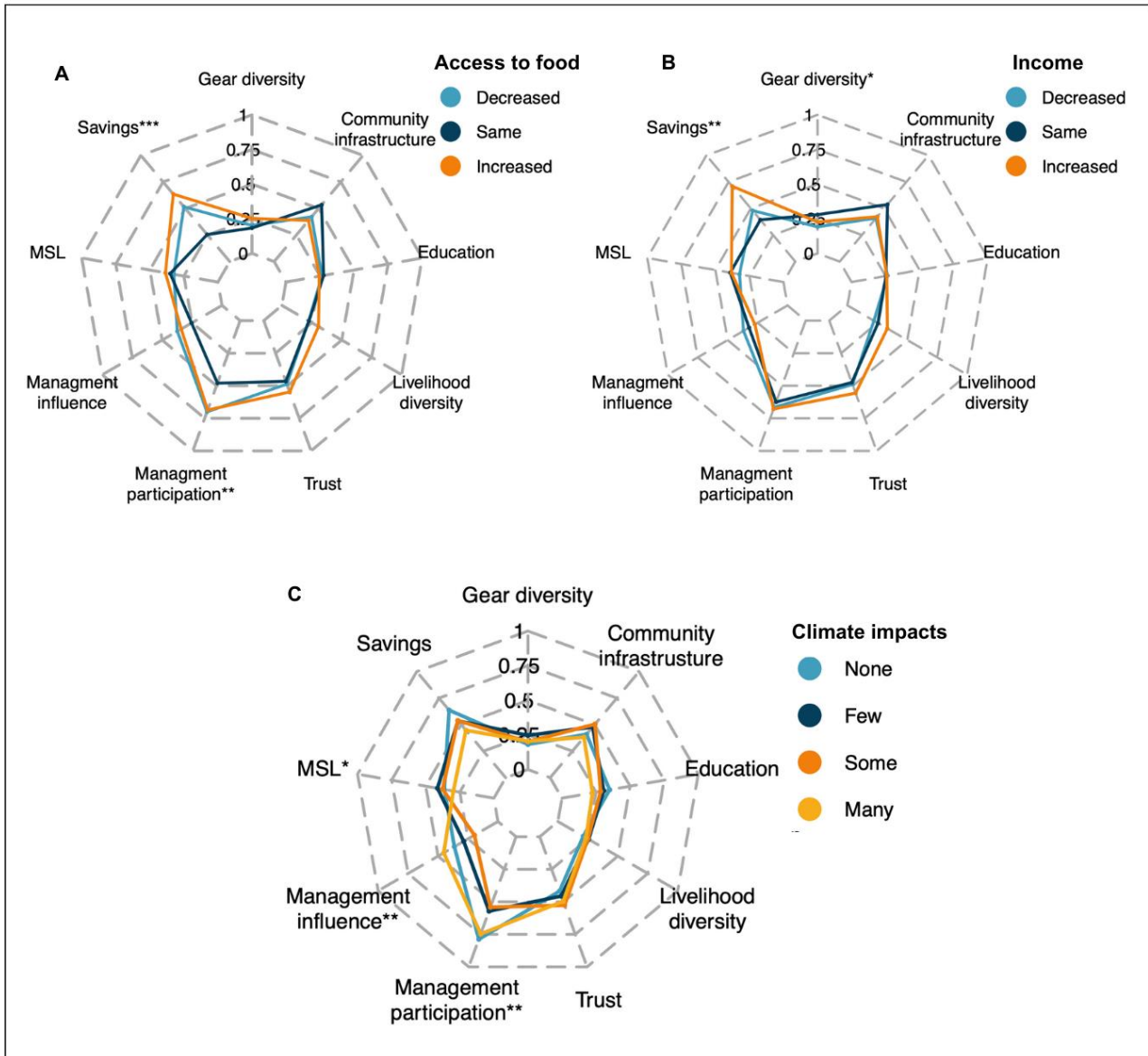


Figure 5.5 Relationship between adaptive capacity indicators and (a) recovery of food access after COVID-19, (2) reported recovery of income after COVID-19 and (C) perceived negative impacts of climate and weather on livelihood . ***p < 0.001; p < 0.01; *p = <0.05;. MSL, material style of life

5.5 Discussion

The ability of coastal communities to respond effectively to both acute and chronic stressors will determine the impact of those stressors on the social-ecological system. In this study, I investigate differences in adaptive capacity between different social groups (including gender, age, and village habitat type) and over time. My findings indicate differences in adaptive capacity among social groups. Comparisons through time showed that only specific adaptive capacity indicators exhibited significant changes between 2016 and 2021, while most remained stable. I also empirically assess the connection between these indicators and the impact of enduring climate events (which can be viewed as chronic disturbances) as well as the reported recovery of income and food access in the aftermath of the socioeconomic repercussions caused by COVID-19 (an acute disturbance). I find that only certain adaptive capacity indicators are significantly associated with the response to disturbance events. Notably, what might be considered 'high' scores of adaptive capacity indicators may not translate to improved reported resilience and recovery. To gain a deeper understanding of these dynamics, I present a discussion of each indicator of adaptive capacity used in this study.

5.5.1 Domains of Adaptive Capacity

Livelihood Flexibility

Flexibility, defined as the ability to switch between livelihood strategies, can be constrained by factors such as financial resources, lack of information and limited opportunities (de la Torre-Castro et al., 2022). Across studies of adaptive capacity within SSF communities, flexibility has been found as one of the most influential domains (Green et al., 2021). Livelihood diversification has long been recognised as an important livelihood strategy for resource-dependent communities (Ellis, 1998; Allison and Ellis, 2001). This importance becomes particularly evident when declining fish catches coupled with limited alternative employment create the risk of poverty traps within fishing communities (Cinner, 2011). In Velondriake, livelihood diversity was strongly related to gender with women more likely to have alternative livelihoods not reliant on fishing. This could potentially be attributed to more time availability as gleaning is primarily limited to the period around spring low tide. It could also be a response to the necessity to find additional income sources due to

declining invertebrate catches during gleaning periods and limited options for adapting fishing techniques (Chapter 5). In contrast, men in Velondriake can diversify fishing techniques, upgrade gear and travel to new fishing grounds to maintain their catch levels (Chapter 5). The findings align with existing literature that suggests women in SSF are more likely to choose livelihood diversification and more willing to exit fisheries (Salgueiro-Otero et al., 2022). For Vezo people, fishing is a way of life (Astuti, 1995). Particularly for men, there is a societal expectation to go fishing as a means to provide daily income and sustenance for the household, thus male fishers that can find ways to remain in the fishery may be more likely to do so (Mohamed Shaffril et al., 2019).

Livelihood diversity significantly increased for both men and women from 2016 to 2021. It is possible that the increase can be attributed in part to initiatives in the region to develop alternative livelihood avenues such as seaweed aquaculture, sea cucumber aquaculture and mangrove beekeeping (Gardner et al., 2020). It could also be reflective of the need to meet increased monetary needs following price increases after COVID-19 (Brayne, 2020). In other SSF communities, the disruption to the fishing industry caused by COVID-19 drove fishers to seek other employment opportunities which they may have continued after the impacts of the pandemic had subsided (Campbell et al., 2020; Ferrer et al., 2021; Rosado et al., 2022).

Despite livelihood diversity being commonly used as a key indicator of adaptive capacity in the face of chronic and acute threats to SSF communities, there was no significant association between indicators of flexibility and the perceived impact of climate events or reported recovery following COVID-19. The absence of a relationship between livelihood diversity and perceived climate event impacts may be attributed to the vulnerability of common non-fishing livelihoods to weather or climate-related disturbances. For instance, events such as cyclones and severe storms can inflict damage upon the aquaculture infrastructure (Ahmed et al., 2019) and periods of drought diminish the productivity of agriculture (Gardner et al., 2016).

In the context of acute socio-economic and social disturbances such as that caused by COVID-19, negative consequences and disruption crossed livelihoods and sectors. For instance, disruptions to trade and services constrained business

opportunities and prevented access to vital goods and services such as food. When the impacts of events are cross-sectoral, the potential benefits of livelihood diversity in mitigating negative effects may be minimized (Mills et al., 2011).

Years spent in education in Velondriake exceeded the mean educational level found in fishing communities in northeast Madagascar (Rabearisoa and Zorzi, 2013). Formal education is often linked to higher levels of social adaptive capacity (Fazey et al., 2007; Wamsler et al., 2012). However, in the study, I observed that perceived climate impacts and recovery from COVID-19 did not show associations with years in education. In other fishing communities in Madagascar, a higher level of education has been associated with greater income (Rabearisoa and Zorzi, 2013). However, the relationship between income and education is not always clear (Maddox and Overå, 2009). The findings may be partially attributed to the disconnect between the skills acquired through formal education and the limited professional job opportunities available in the region (Barnes-Mauthe et al., 2013). Furthermore, formal education may not address the tools and skills needed to anticipate and effectively respond to specific (climatic or socioeconomic) threats (Eakin et al., 2014)

Wealth and Assets

Wealth and assets can facilitate resilience in the face of crises by providing greater opportunities to effectively cope with and adapt to changes (Adger and Vincent, 2005). No significant change was found in access to savings or MSL between 2016 and 2021. This is notable as it could indicate that despite the economic implications of COVID-19, community members were able to manage without erosive coping strategies, for example draining savings and selling assets. Alternatively, if they did use their savings or sell assets, they were able to replenish these resources within a relatively short period. This contrasts with reports from other communities where the economic impact of COVID-19 resulted in the sale of assets and depletion of savings among fishers (Bhowmik et al., 2021; Rosado et al., 2022). There was a non-linear relationship between recovery from COVID-19 and savings, where the people that had savings, were most likely to report improved food access and income, while those that had no savings reported food and access and income had returned to the same as pre-COVID-19 levels. Likewise, there was a similar non-linear relationship between MSL and perceived climate impacts, where the highest MSL corresponded

to the least impact, while the second least impacted group had the lowest MSL. The non-linear relationships observed here may stem from disparities in perception, preparedness, and material well-being, influencing how individuals perceive and experience chronic and acute disturbances (Woodhead et al., 2021). The results do align with other reports, for example in Bangladesh, where financial capital of small-scale fishers was closely related to resilience to the socio-economic impacts of COVID-19 (Bhowmik et al., 2021). These results align with other studies that find that incorporating financial support programs, such as savings schemes and credit access, in community-based management arrangements may support adaptation in the face of acute socioeconomic disturbances (Hattam et al., 2020).

Savings also exhibited variations across different age groups, with the senior age group least likely to have savings. This finding resonates with observations in other fishing communities where the senior demographic tends to possess relatively lower material and financial wealth but exhibits high levels of social capital (Cinner et al., 2015). This pattern may suggest that this group relies more heavily on the support of their social networks to access essential resources and knowledge, particularly in the face of disturbance events.

Access to different fishing gear types is considered valuable because it can offer an adaptive pathway when confronted with changing ecological or climate conditions. For example, fishers with diverse gear can access different fishing grounds and target various species (Pratchett et al., 2008; Cinner et al., 2018). In Velondriake, traditional gender roles in fishing activities mean women are predominantly reliant on one type of fishing gear (spears for gleaning). In contrast, men engage in fishing across various habitats and employ a wide range of fishing gear, although most have a favoured technique that they undertake most often (Chapter 3). Despite these distinctions, I found no significant difference in gear ownership between men and women. Furthermore, gear diversity showed no significant link to association with perceived climate impacts, contrary to its common use as an adaptive capacity indicator in SSF communities in the face of climate change (e.g. Cinner et al., 2013, 2015; D'agata et al., 2020). This result aligns with previous findings that fishers may not perceive benefits from diversifying their gears (McCay, 1981), or that fishers can be limited by capital investment required for new gears (Selgrath et al., 2018). In

Velondriake, gear diversity for fishermen decreased between 2016 and 2021 while the uptake of livelihoods beyond fishing increased, potentially indicating the perceived benefits of diversifying sources of revenue (Allison and Ellis, 2001; Allison and Horemans, 2006).

Community infrastructure encompasses the physical assets and resources that underpin the community's vital functions and services, enabling it to respond effectively to changing circumstances (Pollnac, 1998; McClanahan et al., 2008a). For instance, it supports market accessibility, facilitates access to healthcare services, and enables the flow of essential information. I found distinctions in community infrastructure based on village types. Limited infrastructure is likely to constrain the opportunity for other adaptation possibilities. For example, lower livelihood diversity found in island villages may be partially attributed to limited infrastructure reducing economic opportunities and the development of alternative livelihoods (Mozumder et al., 2018).

Social Capital

Social capital factors including networks, relationships and trust can play a key role in shaping outcomes to disturbance events. For example, social capital may support coordinating collective action and information sharing (Adger, 2003; Pretty, 2003). Social capital developed through co-management in the context of formalised cross-scale relationships can improve post-disturbance trajectories in fishing communities (Marin et al., 2015). This study focused on social networks within the context of natural resource management focusing on attendance and perception of influence at natural resource management meetings. I acknowledge that there are other networks in Velondriake, such as women's groups, likely to influence social capital. However, considering the strong reliance of communities in Velondriake on marine resources for their livelihoods and food security, social capital in the context of natural resource management is significant for overall resilience (Barnes-Mauthe et al., 2015).

Following community-level shocks social capital can break down (Carmen et al., 2022), therefore the stability of social capital indicators between 2016 and 2021, encompassing the events of COVID-19, may indicate resilience of social networks.

This aligns with findings from Barnes-Mauthe et al. (2015) who found high levels of social cohesion between groups in Velondriake. Previous studies have found membership and participation in community groups support resilience to disturbances or shocks (Marin et al., 2015). In Velondriake, social network structures have been found to respond to historical periods of climate-induced resource scarcity (Davis et al., 2023). My findings indicate those with most active participation and influence within natural resource management groups also perceived the most negative consequences from climate impacts. This may be attributed to enhanced access to information by the attendees, leading to a deeper knowledge and awareness of climate impacts (Pelling and High, 2005). This knowledge could in fact lead to improved planning and preparedness in the face of climate events, even though those possessing this knowledge may perceive climate change's impacts as more pronounced (Marin et al., 2015).

In small-scale fisheries globally, women and youth are more likely to be undervalued and unrepresented actors in fisheries management and development equating with lower social capital (Cohen et al., 2016; Fry et al., 2021). This aligns with findings in this study which indicate that in Velondriake, women and youth are less likely to attend management meetings and perceive that they can influence management decisions. This poses a critical challenge for sustainable management as women bring unique perspectives and different knowledge related to their distinct relationships with marine resources (de la Torre-Castro et al., 2022; Baker-Médard et al., 2023). Similarly, empowered and innovative youth are essential for long-term planning for sustainable management (Fry et al., 2021). In Velondriake, community-level decision-making is typically dominated by older and more affluent males (Gardner et al., 2020). In recent years activities have been undertaken to improve inclusivity at the leadership level of the LMMA network in Velondriake and throughout Madagascar, including a national fisherwomen leadership programme (Baker-Médard et al., 2023). Within Velondriake, local efforts have been made to increase female representation in the fisheries association (38% in 2020; Gardner et al., 2020). While these interventions demonstrate increasing recognition of women's contribution to fisheries, a shift in community power structures will occur over long timeframes (Carmen et al., 2022). These time frames are unlikely to operate within the usual timeline of grants or donor funding (Gardner et al., 2020), highlighting the

importance of long-term funding programmes in the context of supporting gender equity and youth inclusion in SSF communities.

5.5.2 Implications for the application of adaptive capacity

The findings suggest that only specific adaptive capacity indicators exhibited a significant relationship with the response and recovery from disturbance events. Notably, high adaptive capacity scores did not consistently lead to improved response or recovery outcomes. Additionally, I observed distinctions in adaptive capacity indicators associated with chronic and acute disturbance events. The results underscore the need for caution when using adaptive capacity indicators as proxies for understanding the resilience of coastal communities and highlight the importance of evaluating the adaptive capacity of a local community using empirical measurement against actual disturbance events.

Furthermore, the social disparity of adaptive capacity found in this research demonstrates that enhancing adaptation is inevitably going to require trade-offs (Ensor et al., 2015). This brings about questions about who makes decisions and which adaptation actions should be prioritised. Normative issues are not a typical focus of adaptive capacity literature, yet considerations of power and equity will be critical to ensure that marginalised groups are not further implicated (Paavola and Adger, 2006). Fostering equitable resilience through adaptive capacity will necessitate engagement from researchers and practitioners that extends beyond adaptation actions, with consideration of power structures and social, cultural, and political change (Matin et al., 2018).

5.5.3 Implications for co-management

Co-management arrangements increasingly encompass social, economic and livelihood objectives to align with the overall purpose of enhancing sustainable fisheries management (Cinner et al., 2012; Jupiter et al., 2014; Gardner et al., 2016). With these interventions come the opportunity to support the adaptive capacity of coastal communities in the face of chronic and acute disturbance events (Armitage, 2005; Marin et al., 2015).

By comparing adaptive capacity between social groups, this study illustrates the opportunity for targeted interventions to ensure co-management benefits in the context of adaptive capacity are reaching different social groups. For instance, supporting programmes to boost the inclusion of women and young adults in decision-making processes (Fry et al., 2021; Baker-Médard et al., 2023), promoting learning and social organisation to support livelihood diversification among men (Salgueiro-Otero et al., 2022) and improved accessibility around financial schemes, such as micro-savings, with awareness raising for older community members. The absence of change in most adaptive capacity indicators from 2016 to 2021 highlights the necessity for sustained, long-term planning to facilitate co-management interventions aimed at enhancing community resilience.

To support the applicability of this research in decision-making within Velondriake, the next steps would be to hold focused discussions on the findings of this chapter with community members, such as the Velondriake Association, Blue Ventures Andavadoaka team, the Madagascar-based members of the Olo Be Taloha Lab and other groups. Given the community's understanding of complex social-ecological processes (Chapters 6 and 7), this would provide an opportunity for findings to be discussed, debated and contextualised in a framework of local knowledge and local experience of sociocultural factors. This aims to increase the usability of this work by supporting the identification of problems and solutions, building on already existing knowledge in the community (Buffa et al., 2023).

5.6 Caveats and Future Research

In this study, I employ indicators to characterise the concept of adaptation, a highly dynamic and multidimensional phenomenon. By comparing adaptive capacity at two different time points, and from two different modes of events (climate change and pandemics), I aimed to investigate temporal dynamics, yet the study does not allow a definitive demonstration of causality in the observed changes. I explore the connection between adaptive capacity indicators and both chronic and acute disturbances; however, these findings are subject to individual perceptions of vulnerability and recovery which is likely to be impacted by other influences not captured in the indicators. Moreover, the findings do not allow assessment of the

level of influence each indicator may have on adaptive capacity. To further enhance understanding in this field, future research should focus on gathering data before and after a disturbance event using panel data that tracks individuals over time. This approach would provide valuable empirical evidence regarding how adaptive behaviours relate to such events and such insights would enable more targeted interventions for the community co-management to support adaptive capacity. Furthermore, explicitly comparing villages where co-management measures and programmes are present and villages, where co-management does not exist, would help provide empirical evidence for the influence of co-management on adaptive capacity.

5.7 Conclusion

This study investigated social and temporal dynamics of adaptive capacity indicators in small-scale fishing communities in Madagascar. There are three key findings, each of which has implications for promoting prescient decision-making in co-management contexts, and for future research.

Certain indicators of adaptive capacity are differentiated by social

group: Based on the indicators used, adaptive capacity was found to be differentiated between social groups. In particular women and youth had lower adaptive capacity in the domain of social capital, and livelihood diversity was differentiated between gender and village habitat type. This differentiation of apparent adaptive capacity between social groups suggests that socially targeted interventions could further improve the potential adaptive capacity benefits of co-management activities.

Relative stability of indicators across 2016-2021: Of the seven adaptive capacity indicators only two showed a significant change between 2016 and 2021. This was livelihood diversity, which increased for both men and women, and, fishing gear diversity, which decreased among men. This relative stability of the majority of adaptive capacity indicators is especially notable as the 2016-2021 period included the most impactful socioeconomic disturbances caused by COVID-19. Although this study cannot demonstrate causality, there is potential that livelihood diversification

strategies that were undertaken within the framework of co-management of local marine resources impacted these aspects of adaptive capacity, indicating the potential for co-management programmes to support sustainable resource management while also increasing adaptive capacity.

Not all adaptive capacity indicators correlated with actual and perceived impacts and recovery: This study investigated the relationship between adaptive capacity indicators and the perceived impact of chronic climate stressors and the recovery of food access and income following the acute socio-economic disturbance of COVID-19. The results indicate that only certain adaptive capacity indicators were significantly associated with impact and response from disturbance events, and these indicators differed between the type of disturbance. These findings underscore that caution is required when using adaptive capacity indicators as proxies for community adaptive capacity in the absence of locally-derived empirical evidence of actual adaptive behaviour and impacts in the face of disturbances. Further, they highlight the importance of differentiating between 'generic' aspects of adaptive capacity that span most disturbance types (acute and chronic) and in most contexts, as opposed to those aspects of adaptive capacity that are highly context and disturbance specific.

To support the applicability of this research in the context of Velondriake, the next stage would be to facilitate a dialogue with local community members to help contextualise findings with existing local knowledge. This will help ensure the findings reported here can build on existing local knowledge to support locally-led decision-making for adaptation and resilience in the face of diverse disturbances.

5.8 Chapter Afterword

This chapter contributes to Research Objective 3 of this thesis by increasing understanding of the dynamics of adaptive capacity in the Velondriake LMMA. While my investigation was specific to communities in the Velondriake region, the findings are likely relevant to other reef-dependent communities in Madagascar and the wider coastal tropics. Subsequent research chapters build upon these insights, exploring how fishers' knowledge and perspectives of change influence adaptation strategies.

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Chapter 6: Integrating fishers' knowledge to investigate social-ecological dynamics and climate change in small-scale fisheries in Madagascar



Preparing the catch in the village of Tampolove. Image: ACarter

6 Integrating fishers' knowledge to investigate social-ecological dynamics and climate change in small-scale fisheries in Madagascar

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Author Contributions: AC conceived the idea. AC developed the survey methodology with input from SNMS. AC and SNMS led the data collection. AC led data analysis on ecological and social data. AC led data analysis on climate data with input from APS. AC wrote the first version of the manuscript. APS, AT and AMWW reviewed the manuscript text.

6.1 Chapter Foreword

This study integrates local knowledge and scientific approaches to examine catch trends and climate variability and change in the Velondriake LMMA over the past generation. It includes an investigation of historical accounts of ecosystem change, long-term catch trends based on fishers' perceptions and fishers' insights on localised variability and change. Additionally, we explore fishers' perception of- and adaptation to- ecological and climate stressors. Many of the interviews conducted with fishers for this chapter were also filmed. A discussion of the use, dissemination, and impact of these videos is provided in Section 6.7.

My motivation for this chapter came from finding a lack of available data on long-term fisheries trends and localised climate impacts on small-scale fishing communities in Madagascar. Recognising that Vezo communities possess a wealth of knowledge on these subjects, I was eager to investigate how this knowledge could be effectively combined with modelling approaches to increase understanding of ecological and climate trends over the past generation. In Chapter 5, an investigation of adaptive capacity indicators revealed social dynamics of adaptive capacity in Velondriake. Building on the findings of Chapter 5, this chapter investigates actual

adaptive behaviour undertaken by fishers in response to the ecological and climate trends that they report.

This chapter contributes to Research Objectives 1 and 2 through an investigation of social-ecological dynamics and methods of adaptation in response to climate and ecological change in Velondriake. It also contributes to Research Objective 4 by presenting a methodology to combine fishers' knowledge with scientific approaches to provide systematic evidence for ecological and climate trends.

Start of submitted manuscript

6.2 Introduction

Overexploitation of marine fisheries, coupled with anthropogenic-induced climate and environmental change, poses a significant threat to marine biodiversity and ecosystem functioning (Cheung et al., 2013; Eddy et al., 2021). This global issue not only threatens marine life but also endangers the livelihoods and food security of millions of people residing along the world's coastlines (Garcia and Rosenberg, 2010; Barnett, 2011; Maire et al., 2021). Of particular concern are small-scale fisheries (SSF), which account for over 90 per cent of the total fishing population (FAO, 2020). These fisheries are often data deficient, unregulated and face complex management issues (Salas et al., 2007; Kelleher et al., 2012).

In SSF scenarios, fishers' local ecological knowledge (LEK), developed through long-term ecosystem interactions, can provide important insights into ecosystem change (Lapola et al., 2019), climate change impacts (Martins and Gasalla, 2018) and shifts in the social-ecological system (Bernos et al., 2021). For example, fisher's LEK can reconstruct previous ecological states (McQuatters-Gollop et al., 2019), fisheries catch rates (Daw et al., 2011; Castello et al., 2023) and biodiversity (Reis-Filho et al., 2016). Together with quantitative information, LEK can contribute important evidence for fisheries management (Martins et al., 2018, Barclay et al., 2017; McQuatters-Gollop et al., 2019). Furthermore, it can enhance fishers' social and political role through participation in decision-making around natural resource management (Fisher 2015). Incorporating LEK and supporting greater social and

political inclusion of local resource users is recognized as critical to achieving sustainability for the world's most ocean-dependant people (Spalding et al., 2023)

The coastal population of Madagascar faces significant nutrition risks due to declining fish catches (Maire et al., 2021). Official fisheries data in Madagascar is scarce and underreported, with catch reconstructions suggesting catches are more than double the FAO-reported figures (Le Manach et al., 2012). However, an expanding small-scale sector to supply the export market (Le Manach et al., 2011) and increasing quotas provided to distant water fishing fleets contribute to growing fishing pressure (White et al., 2021). Furthermore, declines in catches, reported by several authors, indicate unsustainable fisheries exploitation (Harris et al., 2010; Andréfouët et al., 2013; Lemahieu et al., 2018; Gough et al., 2020; Bernos et al., 2021).

Unsustainable fishing practices are further aggravated by the significant threats and disruptions posed by climate variability and change to the livelihoods of coastal fishers (Badjeck et al., 2010; Islam et al., 2014; Cinner et al., 2022). Madagascar is often cited as one of the world's most climate vulnerable countries (Kameni Nematchoua et al., 2018; Rakotoarison et al., 2018). In Madagascar, interannual climate variability is linked to sea surface temperature anomalies caused by the climate phenomena of the Indian Ocean Dipole (IOD) and the El Niño Southern Oscillation (ENSO; Endris et al., 2019). Anthropogenic warming is predicted to increase temperatures across the island by a mean of 1.1 °C to as much as 3.0°C by the end of the 21st century (Hannah et al., 2008; Tadross et al., 2008; Kameni Nematchoua et al., 2018). It remains relatively uncertain how global climate change interacts with interannual phenomena such as ENSO and IOD (Endris et al., 2019), however, an increase in the frequency of floods, droughts and cyclones in recent years may indicate the effects of climate change are already being felt (Tadross et al., 2008; Harvey et al., 2014; Carter et al., 2022). Climate conditions have a direct impact on the livelihoods of fishers through reduced fishable biomass (Cheung et al., 2010), disruptions in fishing efforts and increased physical risks for fishers (Farquhar et al., 2022).

The combined impact of climate change and overfishing on coastal communities will be shaped by diverse social dynamics, including the communities' capacity to anticipate and respond to these pressures (Cinner et al., 2018). Efficient management of small-scale fisheries necessitates a multifaceted approach that considers ecosystem history (Pauly, 1995) and addresses key pressures such as climate change (Frazão Santos et al., 2020) and social-ecological dynamics (Cinner et al., 2018). However, integrating these considerations is challenging (Jupiter et al., 2014), especially in regions where capacity and resources for monitoring is low (Lam et al., 2020). While assumptions about declining catches and regional climate records can offer insights into the potential impacts on fishers' livelihoods, localised studies can provide critical information for locally relevant management interventions (Bernos et al., 2021).

This study is focused on the coastline of southwest Madagascar, home of the Vezo, a semi-nomadic ethnic group (Astuti, 1995) with a culture strongly tied to the ocean for over 1000 years (Marikandia, 2001; Barnes-Mauthe et al., 2013). Despite the establishment of locally managed marine areas (LMMAs) in the region, there is a dearth of long-term ecosystem monitoring data and an incomplete understanding of how to address the complex impacts of climate change and declining fish catch on Vezo communities. Vezo communities possess a wealth of knowledge through lived experiences of ecosystem change that have great potential to inform conservation planning and management strategies (Langley, 2012; Lemahieu et al., 2018; Douglass and Rasolondrainy, 2021). Of particular value, are the insights held by the elders in Vezo communities who represent the last generation with first-hand memories of the marine ecosystem before the onset of large-scale industrial fishing (White et al., 2021), the intensification of small-scale fishing efforts driven by the international seafood exports (Le Manach et al., 2011) and the detrimental impacts of habitat destruction associated with destructive fishing practices (Andréfouët et al., 2013) and climate change (Gudka et al., 2018). Vezo communities traditionally pass ecological and climate knowledge through oral histories (Douglass and Rasolondrainy, 2021). However, following the dismissal of local knowledge systems during the French colonial period (Baker-Medard, 2020) and as a result of the socioeconomic changes described above, there is increased fragmentation of these oral traditions (Lillette, 2006; Douglass and Rasolondrainy, 2021). Given that 39% of

the population in Madagascar is under the age of 14 (World Bank, 2023), the LEK of the current adult generation of Vezo fishers holds critical importance for the understanding of ecosystem reference levels to inform fisheries management.

In this context, the objective of this study is to integrate fishers' knowledge with scientific methods to investigate dynamics of catch decline and climate change in southwest Madagascar over the past generation. To this end, we aim to (1) document historical accounts of ecosystem change; (2) model catches over time using fishers' perceptions; and (3) compare fishers' perception of climate with reanalysis climate data to provide localised climate insights. Additionally, we investigate fishers' adaptation strategies and explore the societal factors that will influence response to climate and ecological change to suggest evidenced-based and locally relevant conservation and management strategies.

6.3 Methods

6.3.1 Study Area and Context

The southwest of Madagascar is semi-arid with annual rainfall between 500 and 700 mm per year. The dry season lasts from April to October and the average temperature is 24° and 27°C (Weiskopf et al., 2021). The coast comprises of diverse ecosystems including mangroves, sea grass and extensive areas of coral reefs (Nadon et al., 2008; Rakotomahazo et al., 2019; Wallner-Hahn et al., 2022). This study was conducted in the village of Andavadoaka within the Velondriake Locally Managed Marine Area (LMMA; 43°13'30 E, 22°04'22 S), 150km north of the regional capital of Toliara (Figure 6.1). The Velondriake LMMA stretches along 40km of coastline, it is currently home to approximately 8000 people of Vezo identity living in 35 coastal villages. For those living in the LMMA, seafood provides 99% of protein, and 87% of the adult population derive their livelihoods from small-scale fishing (Barnes-Mauthe et al., 2013). Participatory fisheries management first began in Andavadoaka in 2004 when NGO Blue Ventures supported trial periodic fishery closures for octopus (Cripps and Harris, 2009). Over the past two decades, the LMMA has incorporated a growing number of management practices including numerous periodic fisheries closures (primarily for octopus) located on reef flats, five permanent coral reef reserves and two mangrove reserves. There are also gear-

based restrictions prohibiting the use of poison fishing and fishing with mosquito nets (Gilchrist et al., 2020). The LMMA was officially gazetted as a protected area in 2015 and is governed by the Velondriake Association, a committee of local leaders. The LMMA is regulated by a *dina* – locally developed laws that become locally ratified (Andriamalala and Gardner, 2010). Blue Ventures continues to provide key resources and technical support for the LMMA and supports education and health programs in the region (Gardner et al., 2020). Since their arrival in 2004, Blue Ventures has supported ecological monitoring of the coral reef ecosystems and collected landings data from 2011 to 2018. Before this period, regular ecological monitoring was not undertaken (Blue Ventures, Pers Comm.).

Fisher practises in Velondriake are gender specific. In general, men use non-motorized wooden dug-out canoes and employ diverse fishing practices including line fishing, net fishing and free diving using spears. Men target a diverse range of finfish and will also target subtidal octopus while freediving (Barnes-Mauthe et al., 2013). In contrast, women predominantly glean invertebrate marine species (particularly octopus, sea urchin and sea cucumber) on reef flats using rebar or spears (Gough et al., 2009). Their activity is restricted to low tide for a four to seven day period during each spring tide while the water is low enough to access the reef flat on foot (Westerman and Gardner, 2013).

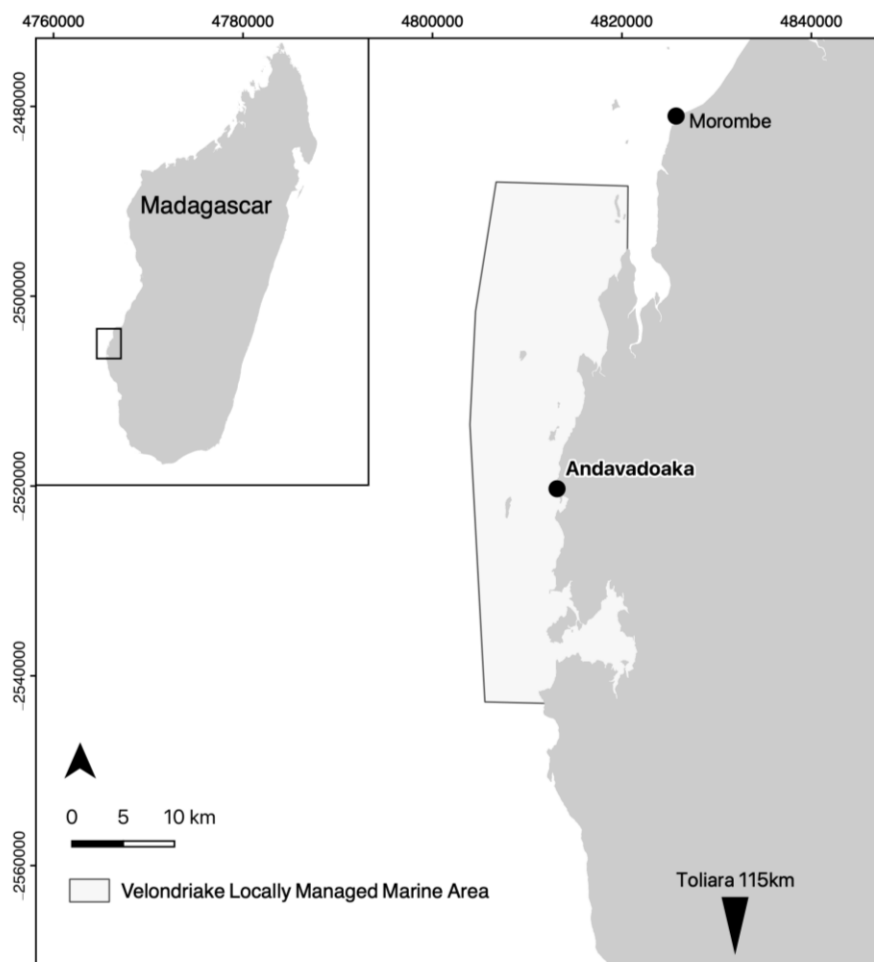


Figure 6.1. The location of Andavadoaka and the Velondriake Locally Managed Marine Areas and the nearest urban centres in southwest Madagascar

6.3.2 Interview Strategy

We employed a combination of semi-structured and key informant interviews with fishers in the village of Andavadoaka between November and December 2022. All interviews were undertaken in Vezo dialect and led by local Blue Ventures staff. We defined fishers as people who regularly extract marine resources for subsistence or commercial purposes (FAO, 2015).

We undertook 65 semi-structured interviews (36 men and 29 women). We employed a purposive rather than random sampling technique to ensure efficient representation of fishers across genders and ages (Mason, 2017). The semi-structured interviews lasted between 10 and 30 minutes. The initial interview questions focused on the respondents' age, fishing history including at what age they

began fishing, their primary fishing practice and what species they targeted. See Appendix 3.1 for the survey question sheet.

The next part of the interview focused on temporal trends in catch sizes. Fishers were asked to recall their typical catch size for the period when they first started fishing and for the present day. The survey methods were based on other studies documenting fishers' recall of fish catch (Daw et al., 2011; Thurstan et al., 2016; Lemahieu et al., 2018; Castello et al., 2023). We elicited calls of 'typical' catch (Castello et al., 2023), as opposed to the measure of 'good' fish catch chosen by other authors (e.g. Daw et al., 2011; Thurstan et al., 2016; Lemahieu et al., 2018). The idea behind eliciting 'good' fish catch is to focus on memorable events and therefore minimise bias (Tesfamichael et al., 2014). However, comparative analysis of recalling memorable fish catch events has produced varied results (Daw et al., 2011; Thurstan et al., 2016). Furthermore, we hypothesise, that as large catch sizes are often quantified by how many pirogues the catch can fill, maximum catch sizes could be limited by the number of pirogues present. Given that fisheries are generally described by their prevailing conditions and uncertainty around the accuracy of using memorable events, asking fishers to recall typical conditions was recognised as suitable for understanding historic conditions (Castello et al., 2023).

We also undertook key informant interviews with three male and one female village elders in Andavadoaka (age over 60). The interviews lasted 20 to 30 minutes and contained open-ended questions about the informant's experience fishing and perceptions of ecological and environmental change. This method encouraged the respondents to convey what they felt was important to discuss, rather than the researcher directing the topic and discussion (Thurstan et al., 2016).

6.3.3 Interview Analysis

Semi-structured interviews were translated into English at the time of the interview. Key informant interviews were recorded and then transcribed and translated after the interview. For open-ended questions with multiple responses, each response was coded and counted within a designated category. Responses were categorised for (1) reasons for catch decline, (2) adaptations to declining catches and (3) proposed solutions. To incorporate all responses under these categories, where the same

fisher gave multiple responses to the same question, these were treated as separate individual responses (Haque et al., 2021). We organised qualitative historical accounts of ecosystem change through thematic analysis of key informant interviews and semi-structured interviews. We analysed the interviews using NVivo (Version 12, QSR International Pty Ltd).

General Additive Models (GAMs) were used to model temporal changes in average catch sizes reported in the interviews. GAMs are a suitable approach in this context as they allow for non-linear modelling between the dependent and independent variables without the need to specify the functional form of the relationship (Hastie, 2017). We conducted separate GAM analyses for men and women due to the distinctive difference in target catch and use of fishing gear. Therefore, they provide a powerful and flexible approach to model the non-linear temporal trends of average catches. We found the data to be over-dispersed and so used negative binomial GAMs and the restricted maximum likelihood (REML) method (Lindén and Mäntyniemi, 2011). For men, the year was used as a fixed effect and target species and gear type were fitted as random intercepts to investigate the influence of other variation in the model not explained by time. All women identified octopus as their primary target species and gleaning as their fishing activity and therefore, we employed Fisher ID as a random effect. We identified the best models as the models with the lowest corrected Akaike information *criterion* (AICc), highest restricted log-likelihood, and highest explanatory power. We tested the quality of the GAM using the modified Hosmer-Lemeshow test, a p-value above 0.05 indicates a good model fit (Hosmer and Lemeshow, 1980). Pearson's correlation coefficient was employed to examine the association between the current age of individuals and the age at which they began fishing.

6.3.4 Climate Data

Metrological weather station data from the study region is unavailable. We obtained daily temperature from the closest weather station located in Toliara (43° 43' 58.8", -23° 22' 58.8"; Menne et al., 2012), 153km south of Andavadoaka from 1970 to 2022. To investigate trends in other climate parameters we used monthly values from ERA5 reanalysis for the same time frame. ERA5 reanalysis is generated by the European Climate Model ECMWF in combination with satellite data and in situ

observations (Hersbach et al., 2020). Data is provided at a horizontal grid resolution of 0.25°, corresponding to around 31km x 31km. Data is averaged across grid boxes, which means values may not precisely represent climate conditions at an exact location. However, it provides a useful indication of trends and patterns in the climate. The ERA5 parameters used in this study are shown in Table 6.1.

Table 6.1 Climate variables and corresponding ERA5 Indicator

Variable	ERA5 Indicator Name
Surface air temperature	2 metre temperature
Eastward (U) wind component at a height of 10m above the surface of the earth	10 metre U wind component
Northward (V) wind component at a height of 10m above the surface of the earth	10 metre V wind component
Precipitation	Total precipitation

6.3.5 Climate Analysis

Time series analysis on monthly climate values was used to investigate trends in climate variables. We tested significant linear trends using a Mann-Kendall test. Mann Kendall is a non-parametric test which supports investigations of trends over time in data which do not meet assumptions of normality. To explore non-linear patterns, the decadal mean was used. Wind direction and wind speed were calculated from the U and V wind components using the formulas in equations 1 and 2. Hereinafter, wind directions are referred to by the direction from which the wind is coming.

Equation 1: wind direction (v is northward wind component, u is eastward wind component)

$$wd = \text{mod} \left(180 + \frac{180}{\pi} \text{atan2}(v, u), 360 \right)$$

Equation 2: wind speed (v is northward wind component, u is eastward wind component)

$$ws = \sqrt{u^2 + v^2}$$

6.4 Results

6.4.1 Historical Accounts

Historical accounts provided by fishers reveal ecosystem conditions within their lifetime different to what can be currently observed in Andavadoaka. Most comments were focused on the nearshore area (Table 6.2). Many fishers reported species declines directly, while others indirectly described the changes, noting that they now had to fish or glean further offshore to achieve a successful catch.

Table 6.2. An example of quotes from fishers in Andavadoaka on the status of the nearshore ecosystem

Interviewee	Theme(s)	Quote
Male elder	Historic abundance	<i>"We never fished the sharks in deep water but just near right there, we used just the line from the beach into the water with bait in the end of that line"</i>
	Species	<i>"Then there were many different species of sharks that came such as the bull shark, scalloped hammerhead, and the giant trevally as well."</i>
Female elder	Historic abundance	<i>"The octopus was always gleaned nearby before, it was on the beach available, both children and adults could get it. There were a lot of octopus in the past."</i>
	Historic abundance	<i>"Even the sea cucumbers have gone as well, they were very widespread even near the seashore spread like cow dung"</i>
	Historic abundance	<i>"And the sharks, when you start swimming, they were already there, coming when they heard voices of the kids who were swimming"</i>
Female elder	Historic abundance	<i>"I remember being able to see the dorsal fins of the shark from my house and there being lots of fish"</i>

Male adult	Historic abundance	<i>“When it was high tide no one could swim because of the sharks - the sharks came from the north of the village”</i>
	Historic abundance	<i>“The old man could throw the spear from the shore and catch sharks”</i>
Male elder	Historic abundance	<i>“There were not many Vezo before because there were a lot of sharks in the beach, so the people were scared to go out fishing”</i>
	Historic abundance	<i>“Before if we were just talking here, we could see sharks on the beach, we thought ‘there are many beasts in the sea, how can we go out fishing?’”</i>

Historical accounts from male and female fishers were distinct, reflecting their distinct target species and fishing practices. Many male fishers reported getting large catches close to the shore. For instance, one fisher stated: *“In the past, people here in Andavadoaka used to fish nearby the beach and caught fish, but not anymore.”*. Similarly, another fisher mentioned, *“There used to be a lot of fish here, and people could fish near the shore. We could catch the unicorn fish even when we went fishing without a pirogue”*.

Several fishers discussed the disappearance of large marine organisms from the nearshore environment with references to sharks, turtles and dolphins. Some fishers also discussed how the historical presence of sharks influenced their fishing practices (Table 6.2). When asked about the target species they no longer encounter in their catches, fishers offered a wide range of species. Most fishers indicated that while these species had experienced declines, they had not vanished entirely. For male fishers, the red snapper species and emperors were the most frequently mentioned fish that were no longer observed. Women’s observations focused on species that are typically caught by gleaning. No women identified a species that had completely disappeared, but they highlighted significant declines in octopus, sea cucumbers, and certain shellfish.

6.4.2 Temporal Changes in Fish Catches

GAM analysis was used to explore temporal changes in catch weight for male and female fishers (Table 6.3).

Men: To investigate temporal changes in fish catch we analysed 54 observations of catch weights collected from 26 fishermen. Reported catch weights spanned from 1967 to 2022. The average reported catch weights ranged from 1.3 kg to 2000 kg. For the year 2022, the average reported catch weight was 24.2 kg.

Model M2 and M4 performed similarly with $\Delta AICc < 5$ and very close R^2 and deviance explained (Table 6.3). A likelihood ratio test to evaluate the significance of gear as a random effect indicated it was insignificant ($p=0.21$). Therefore, we selected M4 with fish family as a random effect as the most parsimonious model. Hosmer – Lemershow was insignificant ($p > 0.05$) indicating a good model fit. This indicates that variation in catch weight can be partially explained by the fishers' target species. In the best performing model, the smoothed term for time showed the fishermen's perception of average catch sizes was relatively stable from 1967 to the mid-1990s, but from the mid-1990s perceived catch size decreased (Figure 6.2).

Women: To investigate temporal trends in octopus catch, we analysed 48 observations from 25 fisherwomen. The observations reported catch weight from 1952 to 2022, the average catch weights ranged from 0 kg to 40 kg. The average reported catch weight for 2022 was 1.5 kg.

After fitting the full dataset to the model, we noticed the two data points before 1970 were having a significant effect on the model fit. Since the two data points greatly increased the uncertainty in the model, we removed these from the analysis. When investigating catch weights reported by women, models F1 and F2 performed similarly with $\Delta AICc < 5$ and a close R^2 and deviance explained (Table 6.3). A likelihood ratio test to evaluate the significance of fisher ID as a random effect indicated it was insignificant ($p = 0.53$) and therefore we selected F1 as the most parsimonious model. The Hosmer-Lemeshow test yielded a non-significant p-value ($p = 0.38$), indicating a good model fit. For the best performing model, the smoothed term for time showed the fisherwomen's perception of average catch sizes of

octopus increased from 1977 to 1990. From 1990 perceived catch size decreased (Figure 6.3).

Table 6.3 Average reported catch weight was modelled as a function of time for men and women. For men, random effects include target fish family and fishing gear type. For women, random effects include fisher ID. Terms in the table are Degrees of Freedom, Second-order Akaike Information Criterion (AICc); adjusted R², deviance explained (Dev, expl) and Log Likelihood.

	Model	Random effects	df	AICc	R^{2(ad)}	Dev.	logLik
						expl	
Male	M1	none	5.76	659.33	0.10	0.37	-321.90
	M2	family + gear	15.21	603.76	0.83	0.83	-279.12
	M3	gear	7.70	641.10	0.55	0.55	-310.17
	M4	family	13.17	599.40	0.82	0.82	-280.73
Female	F1	none	8.07	247.29	0.69	0.70	-112.16
	F2	fisher ID	9.02	249.98	0.67	0.71	242.00

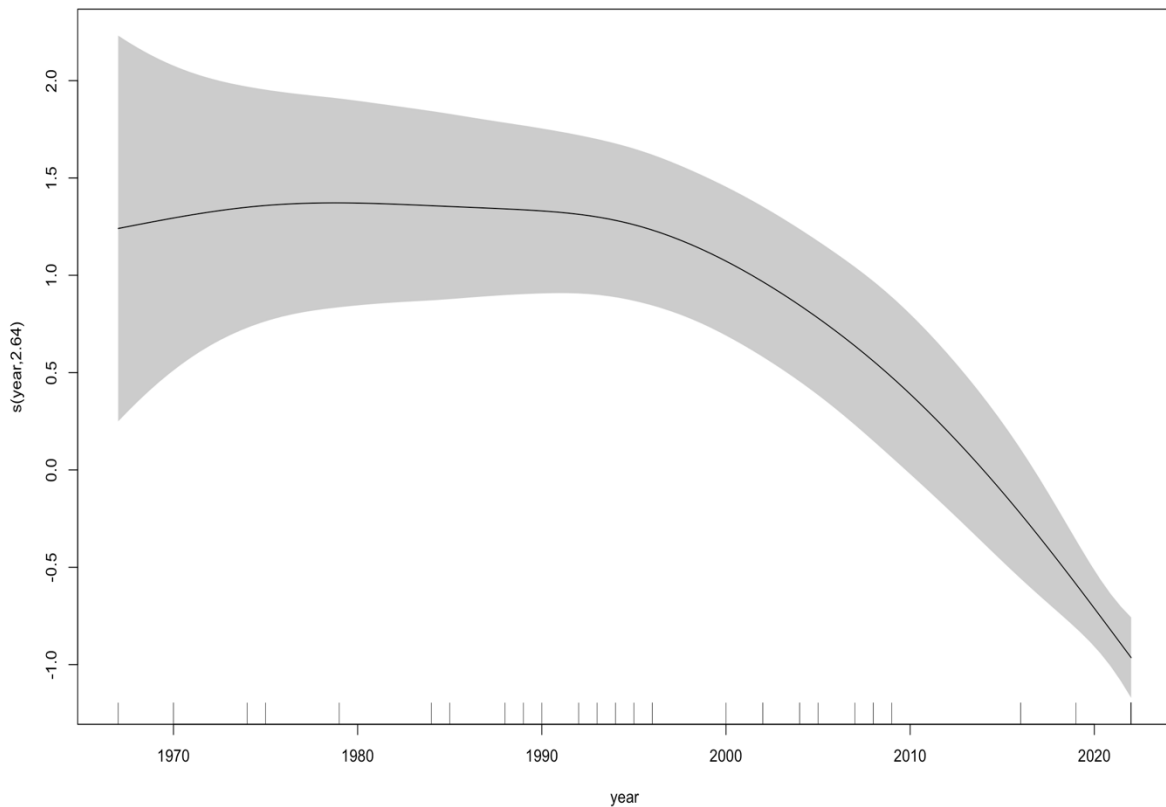


Figure 6.2. Andavadoaka male fisher perceptions of catch changes over time estimated from a generalized additive model (GAM) including the random effect of fish family. The solid black line is the fitted smooth function for time, the grey shading represents the 95% confidence intervals, the rugs on the margins display the location of individual observations. The y-axis of a GAM model represents the partial effect of the covariate on the response, centered around zero. Negative values indicate a decrease in the response, while positive values indicate an increase, considering other estimated terms. The y limits of the plot are set to facilitate the visual interpretation of trends in catch sizes.

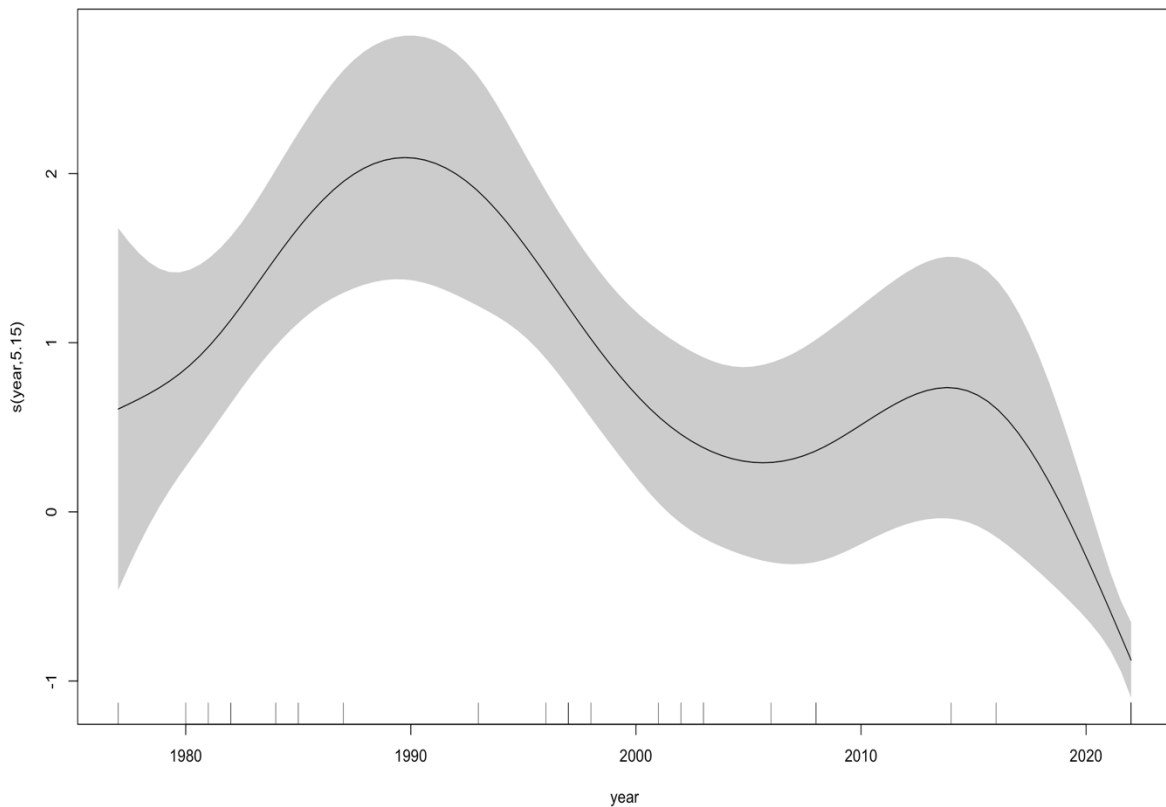


Figure 6.3 Andavadoaka female fishers' perceptions of octopus catch weight over time estimated a generalized additive model (GAM). The solid black line is the fitted smooth function for time, the grey shading represents the 95% confidence intervals, the rugs on the margins display the location of individual observations. The y-axis of a GAM model represents the partial effect of the covariate on the response, centered around zero. Negative values indicate a decrease in the response, while positive values indicate an increase, considering other estimated terms. The y limits of the plot are set to facilitate the visual interpretation of trends in catch sizes.

6.4.3 Fishers' Characteristics and Social-Ecological Perceptions

Characteristics: Results of the interviews are summarised in Table 6.4. We interviewed fishers across all age ranges with a minimum age of 20 and a maximum age of 60. Fishing practices differed between men and women. Men identified their primary fishing practices as: nets (69%), lines (19%), speargun (8%) and gleaning (3%). In contrast, 100% of female respondents reported gleaning as their primary fishing practice. We found no relationship between the age of the individual and the age they started fishing ($r = 0.13$, $p > 0.05$).

Adaption Methods: There was a clear contrast in the adaptations of men and women in response to declining catches. Most women reported they had made no change (15% of men vs 56% of women). Generally, men were more likely to adapt their fishing practises including fishing in different locations (33% of men vs 28% of women), using different gear (42% vs 12%), fishing deeper (39% vs 0%) and adapting their fishing technique (18% vs 0%). A small proportion of men and women (9% and 3%) reported finding alternative income.

Causes: When asked about the causes of change the most popular response in both groups was an increase in the number of fishers (59% of men and 43% of women). Specifically, fishers mentioned an increase in the number of children starting to fish at a young age (16% and 19%). Several men attributed changes to an evolution of fishing practises including the modernisation and/or an increase in the amount of fishing gear (44%), fishing at night (16%), and increasing fishing effort (9%). Men also mentioned shifting location of fish stocks (19%) and catching juvenile fish (13%) as reasons for the change. Popular responses for women were destructive fishing practices (19%). Specifically, women attributed changes as a result of breaking and turning coral upside down when gleaning for octopus. Besides destructive fishing, women also mentioned the temporary octopus reserve as a reason for the decline. There was a perception that the high amount of people gleaning at the reserve opening and/or stealing from the reserve caused octopus populations to decline. Finally, respondents mentioned climate as a reason for changes in the marine ecosystem (9% for men and women).

Solutions: Overall women were more likely to suggest management restrictions when asked about solutions to improve fishery health (32% of men vs 59% of women). Women were also more likely to mention a reduction in destructive fishing techniques (13% of men vs 24% of women) and stopping people stealing from the temporary reserve (0% vs 20%) specifically through rules and enforcement. A small number of men and women discussed restrictions on catching species before they reached reproductive maturity (6% and 7%), and some men mentioned a reduction in fishing at night to improve the fishery (10%). Other themes also included alternative incomes to reduce the number of fishers (19% of men vs. 10% of women)

and removing fishery restrictions (10% and 7%). Men were more likely to offer no solutions compared to women (10% vs 0%).

Table 6.4. Fishing practices, inferred causes, suggested solutions, and coping mechanisms by gender for fishers in Andavadoaka, southwest Madagascar. Columns add up to over 100% as fishers could provide multiple answers.

Topic	Question	Men (%)	Women (%)
Age	Under 30	19.4	17.2
	31- 50	55.6	51.7
	51 +	25	31.0
Fishing Practise	Net	69	0
	Line	19	0
	Speargun	8	0
	Gleaning	3	100
Adaptation	No change	15	56
	Different location	33.3	28
	Improved gear	42.3	12
	Different species	3	8
	Fish deeper	39.4	0
	Different livelihood	9	3
	Fishing technique	18	0
Cause	More people	59	43
	Destructive fishing	6	19
	More children fishing	16	19
	Fisheries management	3	14
	Don't know	3	14
	Increased fishing effort	9	9
	Improved gear	44	9
	Juvenile fish	13	0
	Fish moved away	19	5
	Night fishing	16	5
	Climate	9	9
	Solution	Fisheries management	32
Destructive fishing		13	24
Increase rules and security		0	20
Alternative livelihood		19	10
Remove fisheries management		10	7
Do not fish juveniles		6	7
Stop night fishing		10	0
Do not know		10	0

6.4.4 Local Perceptions and Modelled Climate Change

Nearly all fishers (95%) reported a change in climate since they had started fishing. Fishers' observations on climate fell into four categories: wind, rain, waves and temperature.

Wind: Nearly half of fishers (46%) reported observing changes in wind. Most fishers (36%) reported it was 'windier' or there was 'more wind' now compared to the past. Several of them mentioned that this increase in wind adversely affected fishing and gleaning conditions. Some fishers (13%) noted a shift in the prevailing wind direction; however, there was variation among respondents regarding the specific direction of the change. Others reported the wind being more variable or unpredictable (15%). Alongside wind observations, several fishers (15%) also commented on wave conditions. All reported that waves had got bigger or 'worse' in the context of fishing conditions.

Examining monthly mean wind directions from 1970 to 2022 (Figure 6.4), we only found a significant linear trend in July (Mann Kendall; $p < 0.05$). However, inspecting the decadal average indicates that in recent years wind direction has shifted in a southerly direction in January, February and March compared to previous decades. The figure indicates that wind direction is more variable in November, December and January. When examining windspeed (Figure 6.4), we found November and December had a significant increasing trend (Mann Kendall; $p < 0.05$). The decadal mean indicates that from 2000 to 2010.

Temperature: A small number of fishers reported increasing temperatures (6%). A Mann-Kendall test on time series of monthly average temperatures from both ERA5 climate reanalysis and Toliara weather station indicate a significant positive trend for both ($p < 0.05$; Figure 6.5). Linear trend analysis on Toliara weather station indicates temperatures have increased by 1.87 °C since 1970 and climate reanalysis indicates temperatures have increased by 1.09 °C.

Rain: Several fishers reported changes in rain (38%). Specifically, reports indicated that there was less rain or that rains were arriving later. The timing of the surveys is

significant in this context as they were conducted in November and December, which are considered part of the region's rainy season. During the survey period, the rains had not yet started and therefore it is likely a lack of rain was at the forefront of fisher's minds.

Examining the ERA5 data, we found significant downward trends in total rainfall in July and December (Figure 6.6). However, July is a low rainfall month, and the variation is negligible. On the other hand, a decline in rainfall in December confirms the fishers' observations that rains are arriving later in the year. Investigating total annual rainfall from 1970 to 2022 highlights significant interannual variability. No significant linear trend was found between 1970 to 2022, however inspecting the decadal average shows a downward trend since the mid-2000s. High standard deviation of average rainfall in December, January and February indicates the high variability of rainfall within the rainy season.

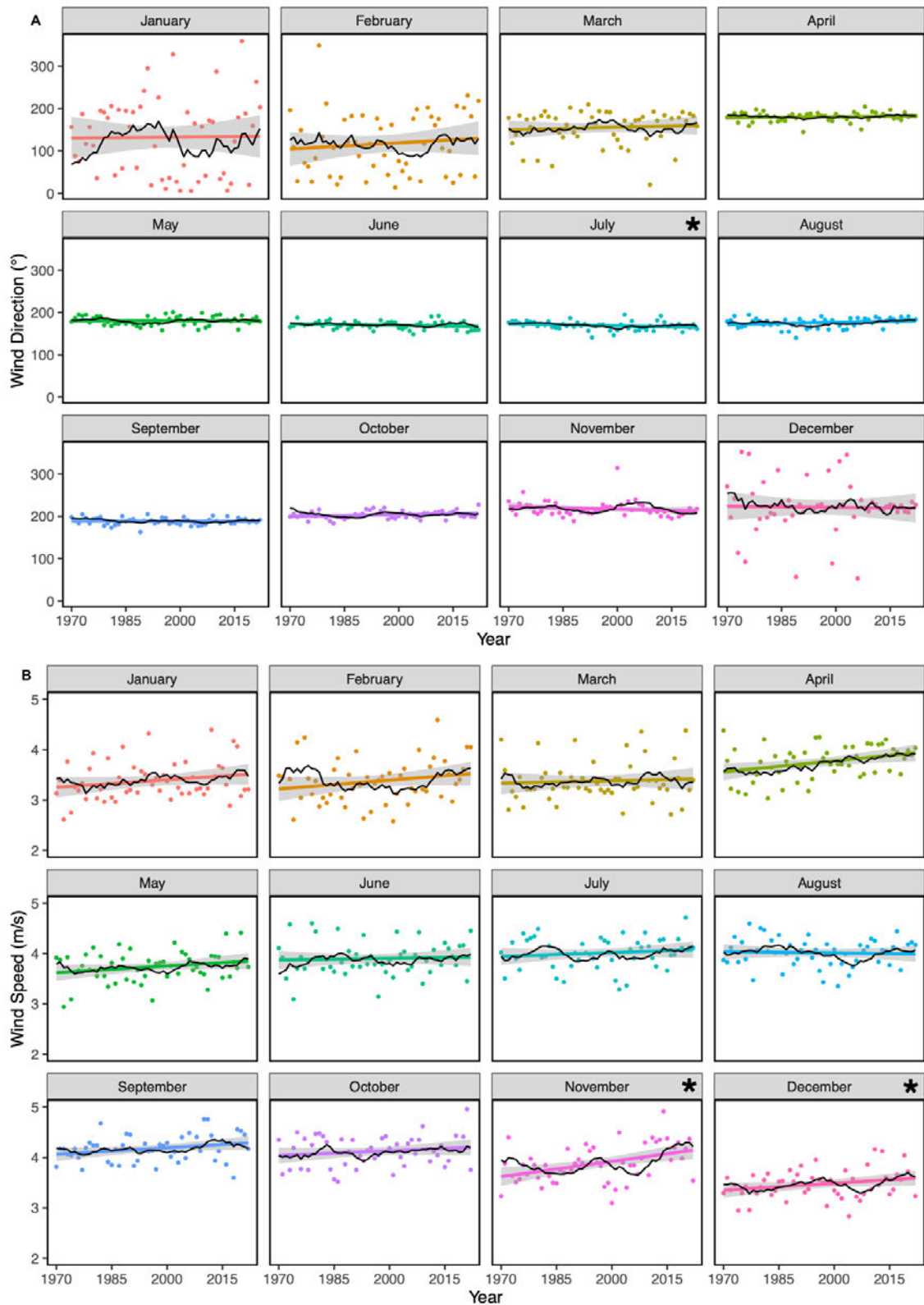


Figure 6.4 Monthly wind data from ERA5 climate reanalysis for the grid box containing Andavadoaka, southwest Madagascar for (A) wind direction and (B) wind speed. Linear trend and 95% confidence interval (straight line with shaded area) and the decadal average (non-straight line). A star indicates a significant linear trend (Mann Kendall $p < 0.05$). Wind directions are indicated by the direction from which the wind is blowing (north (0°), east (90°), south (180°) and west (270°))

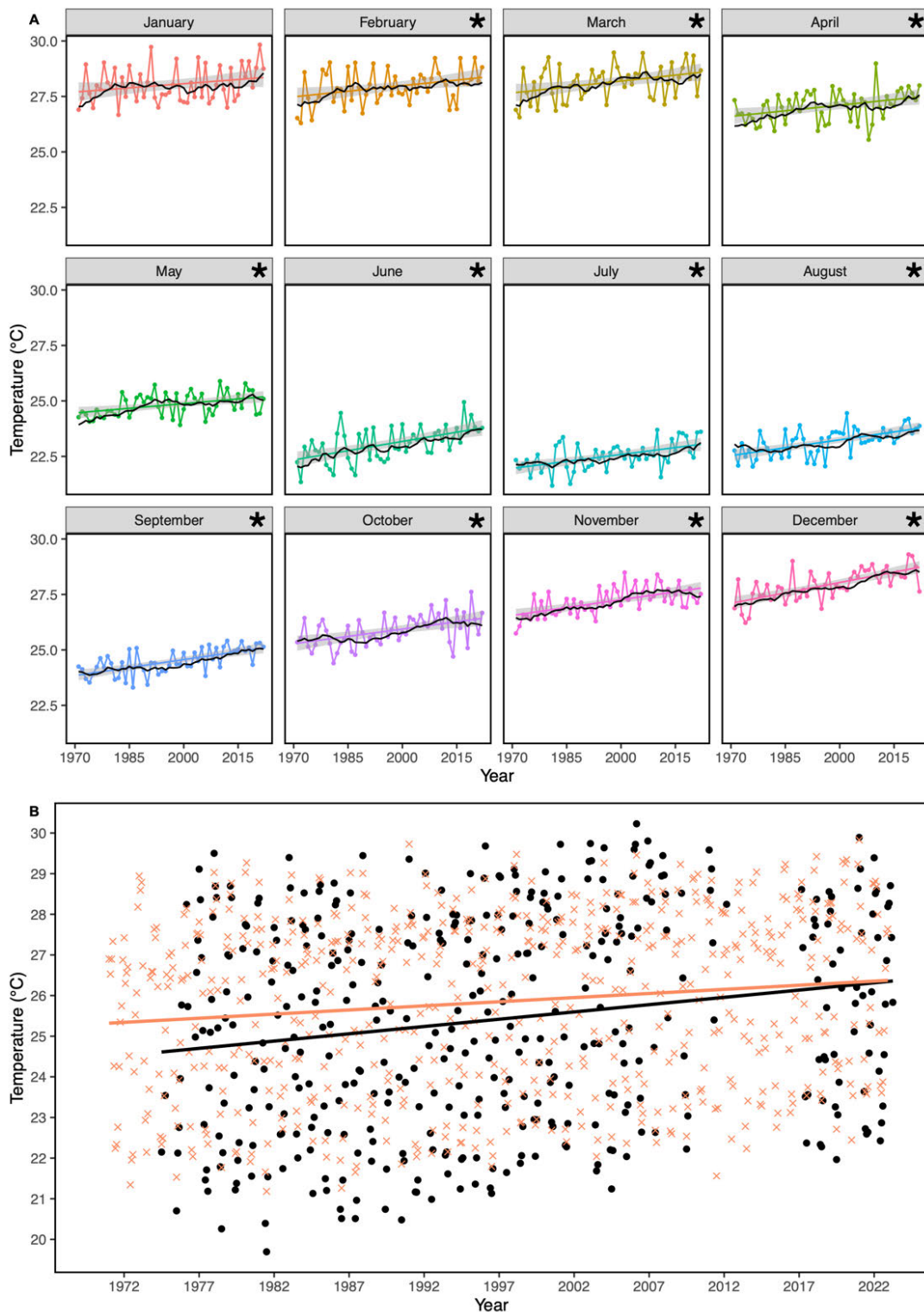


Figure 6.5 (A) monthly precipitation data from ERA5 climate reanalysis for Andavadoaka, southwest Madagascar. Linear trend and 95% confidence interval (straight line with shaded area) and the decadal average (non-straight line). A star indicates a significant linear trend (Mann Kendall $p < 0.05$). (B) mean monthly temperature data from the Toliara weather station (black, solid circles) and ERA5 reanalysis (orange, crosses). Both trends are significant (Mann Kendall $p < 0.05$).

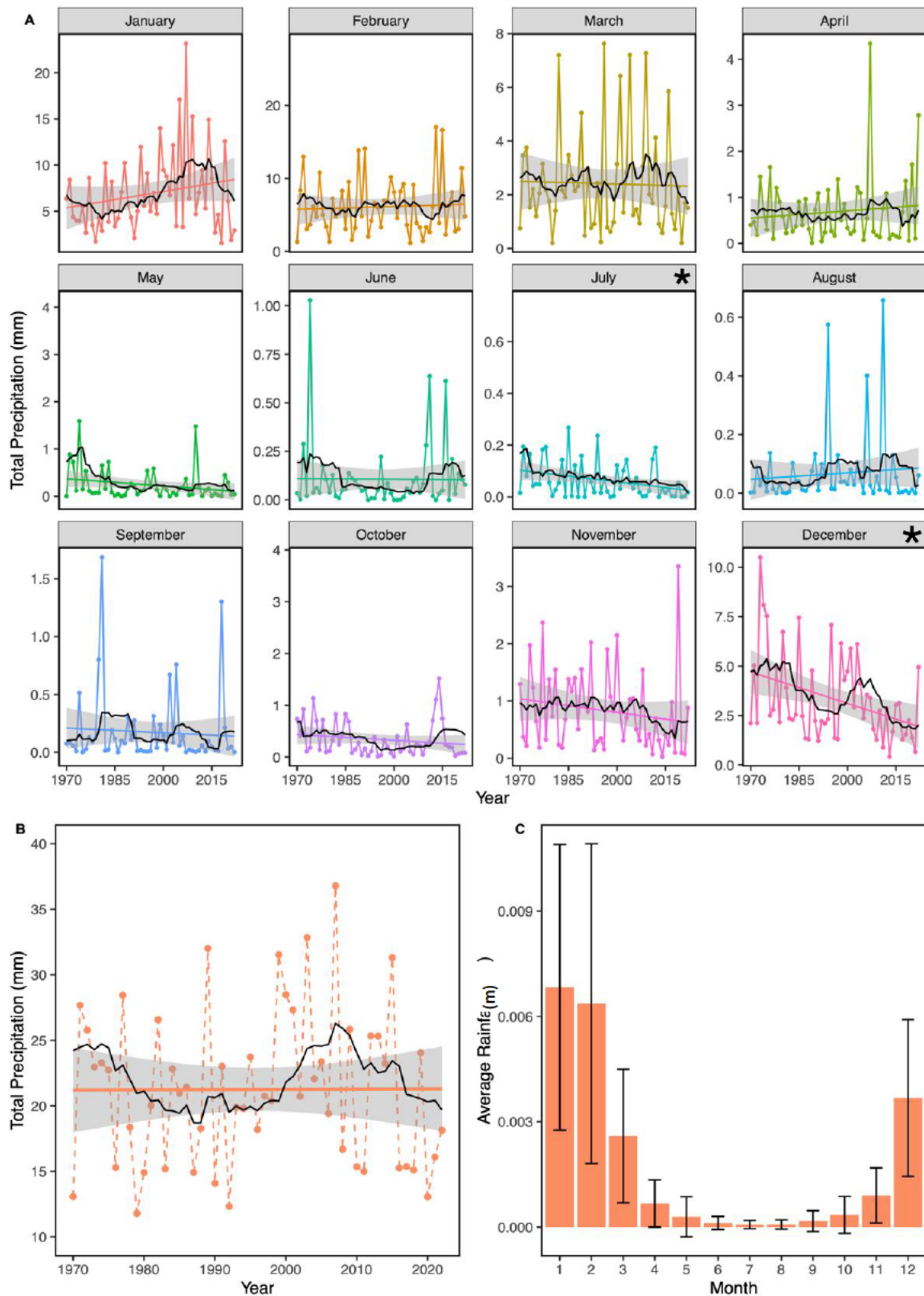


Figure 6.6 Monthly precipitation data from ERA5 climate reanalysis for the grid box containing Andavadoaka, southwest Madagascar. (A) Total monthly precipitation from 1970 – 2022. Note: different scales on Y-axis (B) Total annual precipitation. (A & B) Linear trend and 95% confidence interval (solid line with shaded area) and decadal average (non-straight line). A star indicates a significant linear trend (Mann Kendall $p < 0.05$). (C) Average monthly rainfall for 1970 – 2022. Error bars show standard deviation.

6.5 Discussion

6.5.1 Perception of Climate Variability and Change

Despite containing some of the most climate vulnerable countries (Thornton et al., 2006) and having already experienced widespread impacts from climate variability and change, climate-related research in Africa is severely constrained with limited weather stations and data access (Overland et al., 2022). Previous research has found broad consistencies in climate observations made by communities dependent on natural resources and climate data (Gearheard et al., 2010; Martins and Gasalla, 2018), indicating their potential value to support patterns and trends described in global analysis and fill in gaps where climate data is sparse. Including local perceptions deepens our understanding of the pervasiveness of climate change by providing distinct and relevant local insights on the impacts on societies and ecosystems (Savo et al., 2016).

Unfavourable wind conditions pose significant challenges for small-scale fishers relying on traditional vessels, as it can disrupt fishing efforts and increase physical risks to both equipment and individuals (Heck et al., 2021). Hence, it is logical that wind emerged as the most frequently cited factor when discussing climate with fishers in Andavadoaka. Fishers reported shifts in wind direction and increasing wind speeds and there was a consensus that wind conditions were becoming less favourable for fishing. In the study region, easterly and south easterly winds support good fishing conditions, while southerly and south westerly winds cause choppy seas, making fishing more challenging (Langley, 2012). Based on these parameters, historical remotely sensed data indicates wind conditions have significantly shifted to more unfavourable conditions in certain months. For instance, non-linear analysis shows that over the last two decades, the average wind direction is increasingly from the southwest between January and March (Figure 6.4A). Additionally, we found that wind speed has significantly increased during November and December (Figure 6.4B). These findings align with Farquhar et al., (2022) who found that adverse weather conditions have reduced available fishing hours for small-scale fishing communities on the west coast of Madagascar. Offshore fishing has the greatest risk during adverse wind conditions, as the open water allows for larger waves and swells. As fishers venture further offshore in response to declining catches in the

inshore environment, they may be required to increasingly choose between accessing resources and exposing themselves to greater physical risks.

Over one-third of fishers in Andavadoaka reported declining rainfall, and a small number reported increasing temperatures. These reports are consistent with climate reanalysis data, which shows a decrease in rainfall over the past two decades and a warming trend since 1970. Similar temperature increases were also observed at a weather station located 150km from the study region. High interannual variability in rainfall likely reflects the influence of the IOD and ENSO climate phenomena (Endris et al., 2019). Our findings also align with the research conducted by Randriamarolaza et al., (2022), who analysed data from 28 meteorological stations in Madagascar. Their study revealed a long-term rise in temperatures and a shift towards drier precipitation patterns since 1950. Between 2018 and 2022, the southern region of the country experienced an escalation in drought conditions, leading to increased food insecurity and malnutrition. This was particularly true for inland subsistence communities due to agricultural failure (Rakotoarison et al., 2018). While some fishers perceived a decline in fish catches during periods without rain, they did not offer an explicit explanation for this phenomenon. It is plausible that decreased precipitation affects fishing by altering salinity and nutrient supply, which in turn can influence species distribution (Passos et al., 2013). Prolonged drought conditions may also indirectly impact the marine environment as reduced agricultural opportunities in coastal areas are likely to intensify the reliance on fisheries for food security.

6.5.2 Historical Accounts of Ecological Changes

Fishers in Andavadoaka provided accounts of degraded marine ecosystem, consistent with findings from other studies Madagascar (Bruggemann et al., 2012; Lemahieu et al., 2018; Gough et al., 2020; Bernos et al., 2021). It was predominantly community elders who highlighted the depletion of nearshore areas, particularly in terms of large marine vertebrates, with a specific emphasis on elasmobranchs. Elasmobranchs are targeted by fisheries across Madagascar, yet data on their catch is limited (Humber et al., 2017). Given their long lifespan and low reproductive capacity, elasmobranchs are highly susceptible to overfishing, whether as a primary target or as bycatch (Stevens et al., 2000). Reports of declining shark fishery in

Madagascar date back to the late 1990s (Cooke, 1997; Smale, 1998). In a six-year investigation spanning 2007 to 2012, Humber et al. (2017) found no decline in shark landings, but the catch rate was significantly lower compared to a study conducted in 2002 (McVean et al., 2006) however, the authors noted differences in fishing activity may account for the apparent decline between these studies (Humber et al., 2017). While our study did not quantitatively assess the decline in elasmobranch populations, descriptive accounts can be useful in effectively communicating the magnitude of ecosystem change to a diverse range of stakeholders (Thurstan et al., 2016). In our investigation, we obtained vivid descriptions from elder informants who depicted a thriving population of sharks in the inshore environment, to the extent their presence influenced daily activities. Notably, younger fishers did not share similar experiences. This disparity between age groups indicates potential shifting baseline syndrome, as the younger generation may not have first-hand experience of the historical abundance of elasmobranch populations (Jones et al., 2020; Katikiro, 2014). When incorporating LEK in conservation and marine resource management, the potential bias caused by shifting baseline syndrome should be considered (Fernández-Llamazares et al., 2015). However, given the lack of data on shark populations in Madagascar, these findings highlight the importance for intergenerational knowledge sharing and communication to provide evidence for the implementation of shark fishery management measures within the region.

6.5.3 Perceptions of Catch Change

We analysed male and female perceptions of catch change from 1970 to 2022. Ninety-eight percent of male and female fishers reported decline in catches, regardless of age. The family of the fish species emerged as a significant predictor of fish catch among male fishers, which is not surprising considering the varying catch yields associated with different target species. Reports from male fishers indicate that catches were stable until 1990 followed by a consistent decline from 1990 to 2022. This decline aligns with notable shifts in fish trade in the region (Langley, 2012). Before 1980, trade primarily involved drying fish and local exchange between Vezo and Masikoro (inland agroforester communities). Private international buyers started operating in Andavadoaka in 1980 and from 1990 a large international seafood export company traded with fishers daily. Consequently, it is likely the shift from predominantly subsistence fishing with relatively local-scale trade to satisfying

the demand of international buyers led to unsustainable daily fishing efforts and catch volumes causing catches to decline.

The female fisher's perception of catch change also aligns with the historical timeline of octopus-related trade and management measures in the region. Our analysis indicates an upward trend in catch weights from the mid-1975 to 1990. Prior to the mid-1990s, octopus was dried locally with trade centred around regional hubs. However, a significant shift occurred in the mid-1990s with the introduction of octopus collectors (Langley, 2012), incentivizing increased harvesting efforts and potentially contributing to the subsequent decline in catch weights observed in our analysis. We hypothesise that the increase seen in catch weight in the mid-2000s is related to the implementation of temporary fishery closures within the Velondriake LMMA. The first opening following the implementation closure was in 2005, however, it was not until the second opening in 2006 that the catch weight per fisher increased (146% of pre-closure levels; Benbow et al., 2014). However, our analysis suggests that the reserve's effectiveness in sustaining these catch levels may have diminished over time.

6.5.4 Social-Ecological Dynamics of Ecosystem Change

Our analysis highlights the social dynamics that have driven the trajectory of fisheries in Andavadoaka. Both male and female fishers identified an increased number of people fishing as a leading cause of the decline in catches. This was attributed to an increased population and increased participation in fishing. Both male and female fishers reported an increased role of children in fishing activity, although our analysis indicates there was no relationship between the age of the fisher and the age they started fishing. We hypothesise that while older generations engaged in fishing in a more ad-hoc manner during their childhood, the decline catch yields necessitates greater fishing efforts to support food security and sustain livelihoods. As a result, the role of children in providing fish for their families may have intensified to meet these increased demands.

Male fishers also identified increased fishing effort, improved fishing gear, fish migrating to different locations and fish migrating deeper waters as causes for catch declines. The perception of migration of fish to different and deeper locations likely

reflects the depletion of fish populations near the shore due to intense fishing pressure and the extensive deterioration of shallow reefs caused by coral bleaching (Vincent et al., 2011) and destructive fishing (Andréfouët et al., 2013). Notably, the introduction of spearfishing masks and various types of nylon nets in Andavadoaka between 1960 and 1990 has allowed fishers to target a wider range of species and fish at greater depths (Langley, 2012). Prior to these advancements, the limitations of fishing gear in terms of depth may have provided a refuge for fish populations in deeper waters, thereby contributing to the sustainability of fishery resources (Bridge et al., 2013; Lindfield et al., 2014).

Destructive fishing practices were highlighted by female fishers as a significant factor contributing to the decline in octopus catches. While octopus fisheries have been identified for their potential sustainability due to their resilience to climate change (Sauer et al., 2021), this potential is undermined when their habitat is lost entirely. Elsewhere in southwest Madagascar in the Grand Récif of Toliara, gleaning has been identified as a major driver in the large-scale degradation of the reef (Andréfouët et al., 2013). Interestingly, several women also identified the temporary closure of octopus fisheries as a driver for the decrease, primarily due to extremely high fishing pressure, theft and destructive gleaning techniques. Sustainability outcomes of temporary fishery closures will be affected by the intensity of fishing during the fishery opening. There is potential that elevated fishing intensity when the reserve is newly opened depletes stocks beyond sustainable levels (Russ and Alcala, 2003). This is particularly true when there are high levels of ambient fishing pressure in surrounding areas, reducing the chance of replenishment (Cohen et al., 2013). This suggests, that for period closures to continue to be sustainable, it may become increasingly important to embed temporary fishery closures within management frameworks where there are strong mechanisms to limit destructive fishing and unsustainable fishing outside the reserve areas.

Notably, few fishers identified climate dynamics as a driver of catch decline. Climate variability and change have complex and wide-ranging impacts on fisheries, including declining abundance, shifts in trophic structures, and changes in species distribution patterns (Cheung et al., 2010). However, quantifying these impacts is challenging, and they have likely been overshadowed by more visibly apparent

factors. Consequently, current adaptation measures taken by fishers may not specifically address the challenges posed by climate change. This finding is noteworthy when considering the significant increase in funded projects that prioritize climate adaptation as a crucial indicator (OECD, 2022). Our findings underscore the fact that climate considerations are not always at the forefront of fishers' priorities. Therefore, climate-related solutions should be integrated into a wider framework of strengthening adaptive capacity, addressing the multifaceted challenges faced by coastal communities.

6.5.5 Responses to Decline Catches

To address the decreasing availability of marine resources, fishers must adapt and/or focus on different livelihoods to maintain their food security and income (Benbow et al., 2014, 2014). In subsistence communities, women are more likely to be more severely affected by environmental and climate change due to factors such as their limited ability to diversify, household responsibilities, and cultural barriers (de la Torre-Castro et al., 2022; Pike et al., 2022). In Andavadoaka, we found evidence of a gender disparity in the ability to adapt to declining marine resources. Male fishers predominantly reported actively adjusting their practices by employing more efficient gear and fishing techniques, exploring new fishing grounds, and venturing into deeper waters, which allows them to target a variety of fish species. In contrast, most women in Andavadoaka did not modify their fishing practices. They face limited access to boats, restricting them to nearshore areas, and heavily depend on a single species for their catch. The average daily catch reported by women in 2022 was 1.5 kg. This figure emphasizes the significant vulnerability of female fishers in Andavadoaka, as they operate on a small margin before their catch potentially reaches zero.

The most frequently proposed solution to support the health of fisheries was the implementation of fishery management restrictions. However, women were more likely than men to suggest area-based restrictions and identified the need to improve security and stop destructive fishing techniques. In Velondriake, inclusive governance and promoting the participation of women in decision-making remains difficult as women are less likely to stand for office or contribute to community meetings (Singleton et al., 2019; Gardner et al., 2020). Consequently, our findings

suggest that there is a willingness within the community to adopt increased management measures, but these intentions may not currently translate into active decision-making practices. Addressing these barriers and bridging the gap between intentions and actions requires a multifaceted approach. It is crucial to foster an enabling environment that promotes gender equity and facilitates meaningful participation in decision-making processes. This could be achieved through capacity-building initiatives, awareness campaigns, and targeted interventions that address the specific challenges faced by women in the community (Baker-Médard et al., 2023).

6.5.6 Lessons for Management

Fishers' perceptions indicate that in recent decades, the catch of fish and octopus in Andavadoaka has been declining despite the establishment of the Velondriake LMMA in 2003. While previous studies have demonstrated positive ecological outcomes of fisheries management in the area (Benbow et al., 2014; Gilchrist et al., 2020), our findings suggest these have occurred in the context of long-term fisheries decline primarily a result of social and economic factors driving unsustainable fishing. These results underscore the importance of designing fisheries improvement interventions beyond ecological goals and with the consideration of external social and economic environments (Barr et al., 2019). Strategies could include providing incentives to mitigate short-term adoption costs, employing conditionality agreements to promote sustainable behaviours and discourage non-compliance (Gutiérrez et al., 2011), and adopting a collective action approach, such as partnering with local finance institutions to align fisheries goals with socioeconomic objectives (Anderson et al., 2002). Emphasising equitable participation to accommodate the unique perspectives and roles of both men and women in their interaction with marine resources and their options for adaptation will help ensure management is more comprehensive and effective (Baker-Médard et al., 2023).

6.6 Conclusion

By integrating local knowledge with scientific methods, we can gather valuable evidence to inform marine management decisions in a data-poor region. The perceptions of fishers in Andavadoaka shed light on the degradation of the

nearshore ecosystem and the decline of fisheries over the past generation. Our findings suggest that fisheries catch is closely tied to the local economic and social factors. Fishers demonstrated a keen awareness of climate dynamics, providing localized insights into trends in wind, rainfall, and temperature that align with climate reanalysis data. However, most fishers did not perceive a direct connection between climate variability and change and the decline in catches. Instead, they attributed the decline primarily to social-ecological changes, such as an increased number of fishers, intensified fishing effort, changes in fishing gear, and destructive fishing practices. Our findings also revealed a gender disparity in the ability to adapt to shifting conditions, with men having greater opportunity to actively adapt their fishing practices compared to women. We observed a strong willingness among the community, particularly women, to embrace increased fishery management restrictions. However, barriers to inclusive governance and decision-making processes may need to be addressed to translate these intentions into effective action. Our study emphasises the need for a multifaceted approach to local fisheries management that extends beyond ecological targets and addresses the social drivers of unsustainable fishing, placing a strong focus on inclusive governance. Additionally, it underscores the importance of strengthening resilience of local fisheries management to effectively respond to external large-scale socioeconomic drivers that drive the degradation of fishery resources. By taking these factors into account, we can support coastal communities in Madagascar and throughout the coastal tropics to work towards more sustainable and resilient fisheries livelihoods.

End of the submitted manuscript

6.7 Research Dissemination

Producing usable and actionable science requires building relationships and communication channels between scientists and local stakeholders (Wall et al., 2017; Spalding et al., 2023). Although visual research methodologies were not the focus of this chapter (see Chapter 7), I aimed to ensure that the outputs of this research were usable in the local context which was the motivation for the research team filming many of the interviews using smartphones and an external microphone.

Several interviews have now been included in a film titled “Ocean Futures”, written and produced by co-author S. Maniry Soa. The narrative of Ocean Futures is based on the interview questions from this research chapter, including discussions with fishers about how the marine ecosystem has changed since they started fishing, the main reasons for these changes, and their perception on how the situation can be improved. The film also features interviews not undertaken as part of this research, with fishers from southwest Madagascar discussing their experience establishing near shore no-take zones.

Since its completion in 2023, Blue Ventures has shown Ocean Futures in different settings in Madagascar. This includes at a regional octopus fishery management meeting, training sessions for coastal patrolling and ecological monitoring and coastal villages where Blue Ventures currently provides support or plans to support in the future. The aim of showing the film is to promote conservations about marine conservation, raise awareness about changes in the marine ecosystem and inspire local leadership in the creation of near-shore no-take zones.

Reports from Blue Ventures staff indicate the reception towards the film has been positive and they have observed it instigating discussions in different contexts about management of the near shore marine ecosystem. The film contributed to the decision by one village setting up a nearshore no-take zone (Paul Antion, Pers. Comm, May 2024).

“We’ve shown it, people love the film and now the seagrass no-take zone is spreading in Velondriake area because of this film and also [we] have shown this film in northwest Madagascar, they are really inspired” (Symphorien Mariny Soa, Pers. Comm, May 2024)

“We showed it in new villages where we have not started working in the northwest in the Bay of Mahajamba and immediately the film led to discussions about ‘what are the things we could do reverse this trend’ because [the community] recognised, and especially the elders, that things are changing rapidly and that something needs to be done” (Paul Antion, Pers Comm, May 2024)

The positive reception of Ocean Futures and its tangible outcomes underscore the effectiveness of using visual media to enhance the applicability of research in a local context. By framing the interviews in a narrative, the research outputs are disseminated in a way better aligned with storytelling culture of coastal communities in Madagascar, likely proving more relevant and informative than scientific reports or presentations. This example highlights the value of allowing time and resources for the inclusion of ‘non-traditional’ research methods to complement scientific investigation to improve the applicability of research in social-ecological settings (Rölfer et al., 2022). For a detailed discussion of the ethics of using visual media in research, see Chapter 7.

6.8 Chapter Afterword

In this chapter, I combine fishers’ local ecological knowledge with scientific approaches to expand our understanding of fisheries trends and localised climate impacts in the Velondriake LMMA over the past generation. This chapter contributes to Research Objectives 1 by revealing how fishers are perceiving and responding to fisheries trends and climate change in the Velondriake LMMA. Additionally, it builds on findings in Chapter 4 by indicating gendered dynamics of adaptation options (Research Objective 2). Finally, it also contributes to Research Objective 4 through presenting methodology for collaboration between fishers and scientists to create evidence that can help inform natural resource management and other development interventions.

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Chapter 7: Participatory video as a tool for co-management in coastal communities: a case study from Madagascar



Community filmmakers filming an interview during the “Voices of the Vezo” participatory video project. Image: ACarter

7 Participatory video as a tool for co-management in coastal communities: a case study from Madagascar

The following chapter “Participatory video as a tool for co-management in coastal communities: a case study from Madagascar” has been published in *Frontiers in Human Dynamics*. See Appendix 4.1 for the manuscript abstract and acknowledgements.

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7.1 Chapter Foreword

The way knowledge is created shared and used in society crucially influences transformation processes (Berkes, 2009a). Social-ecological systems (SES) research is acknowledged as crucial for addressing global environmental challenges (Fischer et al., 2015), yet there are several barriers which prevent the uptake, integration and application of SES work in decision-making. This includes the complexity of SES academic concepts (Colding and Barthel, 2019), contrasting knowledge systems between researchers and other stakeholders (Berkes, 2009a; Maldonado et al., 2016) and the need to align research with local priorities (Crompton, 2019).

Acknowledging these challenges during the research for this thesis, I was motivated to design a research chapter where knowledge co-production and proactive sharing

of findings were at the core of the approach rather than a secondary activity. The result was “Voices of the Vezo”, a participatory video project involving four villages in the study region. Leveraging visual methods of knowledge co-production, the project documented and disseminated information on marine ecosystem changes and social-ecological issues faced by Vezo communities. The approach builds on findings in the previous chapters by providing evidence of social-ecological change through local perspectives.

This chapter contributed to Research Objective 3 by offering insights into an activity that can be effectively carried out within a co-management framework to support social and ecological outcomes. Furthermore, it contributes to Research Objective 4 by providing critical review of participatory video as an exemplary method of knowledge co-production.

The Voices of the Vezo films are available at www.voicesofthevezo.org.

Start of published manuscript

7.2 Introduction

Across the globe, marine coastal ecosystems are declining at an alarming rate (Beddington et al., 2005; Henson et al., 2017; Eddy et al., 2021). For hundreds of millions of small-scale fishers in the coastal tropics, this threatens their livelihoods and food security (Beddington et al., 2005; Barange et al., 2014). Over recent decades, community co-management has been increasingly used in management of small-scale fisheries (Miller, 2014). Community co-management moves away from top-down governance and devolves management to local resource users in partnership with other actors. In contrast to the more widely used term ‘community-based management’, community co-management acknowledges that many local communities do not have the financial or technical resources to implement natural resource management independently. Therefore, management initiatives are undertaken in partnership with government and/or non-governmental organizations (NGOs; Cinner et al., 2012). Alongside the co-management partner, co-management

can often involve a diversity of other institutional linkages with the community from local to international scales, including the private sector, donors, practitioners, and researchers (Berkes, 2009b; Cinner et al., 2012).

In Madagascar, as in many low-income economies, scientifically-derived data on the historic and current conditions of coastal ecosystems and human interactions with these ecosystems are limited (van der Elst et al., 2009). When supporting communities to implement resource management, lack of evidence around ecosystem conditions can hamper the ability to make locally-relevant evidenced based decisions (Christie et al., 2021). Furthermore, lack of knowledge of the historical conditions may lead to management decisions that underestimate the recovery potential (or further decline) of the ecosystem (Plumeridge and Roberts, 2017). This can have consequences for biodiversity, but also shift perceptions for the potential services available from the ecosystem, such as food provision (Klein and Thurstan, 2016; Pauly and Zeller, 2016). Alongside ecosystem knowledge, it is critical that co-management plans consider the social-ecological dynamics of the local context: specifically, how people experience ecosystem change in relation to their livelihoods and well-being. Gaining an understanding of underlying cultural, economic and nutritional ties to natural resources is fundamental for effective and sustainable management (Bennett and Dearden, 2014; Stephanson and Mascia, 2014).

Local ecological knowledge (LEK) refers to knowledge constructed not by subject-area experts but by local resource users and community managers (Berkes, 2009b). It can provide in-depth understanding into both historic ecosystem trajectories (Brook and McLachlan, 2008) and social-ecological dynamics (del Mar Delgado-Serrano et al., 2015). Increasingly, under co-management frameworks, conservation researchers and practitioners are employing methods which engage LEK to help ensure research and interventions are locally relevant and serve on-the-ground needs (McMurdo Hamilton et al., 2021). The collection and incorporation of LEK can also provide opportunities to develop local capacity, sense of agency and conservation ethic, together providing a foundation for resource management in the local community (Granek and Brown, 2005).

In co-management arrangements, power sharing between local communities and other stakeholders (e.g., NGOs, government or private sector) can pose inherent challenges. Nonetheless, these power imbalances can be alleviated through effective dialogue, knowledge exchange, and open discussions of issues (Borrini-Feyerabend et al., 2007; Berkes, 2009b). Participatory video (PV) is a method that promotes the synthesis of community knowledge by supporting a group to create their own film around a specific issue. The visual and oral mode of engagement can encourage marginalized groups to contribute, documenting knowledge and voices of those in society that are often unrepresented in decision-making spaces (Tremblay and Jayme, 2015; Mistry et al., 2016a). New ideas and issues faced by participants in the PV process may challenge local perspectives and inspire agency over local solutions (Tremblay and Jayme, 2015; Cai et al., 2019). The PV process can also cultivate political capacity, empowering participants to ‘make their voices heard’ (White et al. 2003). PV films are often shared with the wider community, external agencies and decision-makers as a tool to directly communicate local perspectives (Thompson et al 2017). This can help inform management actions that are effective and relevant in the local social and ecological context (Beh et al., 2013), as well as the validation and empowerment of local voices and views on managing resources. For example, in Turks and Caicos, a PV process used to gather stakeholder perspectives on the local sea turtle fishery resulted in formal amendments in fishery legislation (Christie et al., 2014). In the context of ecosystem change, PV provides a platform to collate local knowledge and can reveal issues which the researchers may have missed (Calheiros et al., 2000) and/or are not usually shared between different community members or cohorts (Mistry et al., 2016b).

In this paper, we describe the process and outcomes of a pilot PV project titled *Voices of the Vezo* (VOTV), undertaken between October and December 2022 in four traditional fishing communities in southwest Madagascar. We describe engagement with and outputs from the PV process and then consider its potential as a tool in conservation co-management contexts. We also discuss the practical challenges faced during the VOTV project and make recommendations for co-management organizations, communities and/or researchers considering using PV in the future.

7.3 Materials and Methods

7.3.1 Study Context

Madagascar is the fourth largest island in the world and despite considerable natural resources, 81% of people live below the international poverty line and 33% of the population is food insecure (World Bank, 2023). Madagascar's community-based small-scale fisheries are of major importance for the population inhabiting the extensive coastline (Le Manach et al., 2012). Over half of all fishers operate in the Toliara province in the southwest of the country (Laroche and Ramananarivo, 1995). This region is largely populated by traditional Vezo fishing communities whose cultural identity has been strongly tied to the ocean since their arrival in Madagascar some 2000 years ago (Astuti, 1995). Poor transport infrastructure, an arid climate and low agricultural productivity in southwest Madagascar mean there are very few economic or subsistence alternatives to traditional fishing and reef gleaning (Harris, 2007). Therefore, the livelihoods of Vezo people remain highly dependent on the ocean with the small-scale fisheries sector employing 87% of the adult population and providing 99% of protein for household meals (Barnes-Mauthe et al., 2013). In the past two decades, collaborative efforts between NGOs and commercial companies have been dedicated to reducing dependence on fisheries while creating alternative income sources in the region. This has led to the development of community-based aquaculture (CBA) of seaweed and sea cucumbers (Eeckhaut et al., 2008; Ateweberhan et al., 2015, 2018). The products of the CBAs are sold primarily for international export.

The coastal environment of southwest Madagascar includes extensive areas of seagrass and mangroves with large areas of coral reef including the Grand Récif de Toliara, the third largest reef system in the world. Vezo fishers employ a wide variety of gear and fishing techniques depending on their target species (Gough et al., 2009). In general, line, net and spear fishing from a non-motorized pirogue (open dug-out canoe) is undertaken by men while women glean in the intertidal area. Gleaning in this context is primarily walking the reef around the period of spring low tide to collect marine invertebrates including octopus, sea cucumber and urchins. Unsustainable fishing activity is rapidly degrading Madagascar's coastal ecosystems, driven by both international seafood export demand (Le Manach et al., 2011, 2012)

and a growing population (Brenier et al., 2011). Population increase has been attributed to coastward migration of inland communities in response to declining agricultural productivity (Bruggemann et al., 2012) and high birth rates due to lack of access to family planning services (Harris et al., 2012). The adverse effects of overfishing are further compounded by destructive fishing practices such as poison fishing, beach seining and the destructive methods of invertebrate collection (Gough et al., 2009; Andréfouët et al., 2013). Direct pressures are exacerbated by climate disturbances including coral bleaching caused by marine heatwaves (McClanahan et al., 2007; Gudka et al., 2018), and destructive cyclones that reduce coral cover (Carter et al., 2022).

7.3.2 Study Sites

The PV workshops took place in four villages located between 135 km and 150 km north of the regional capital of Toliara (Figure 7.1). Three of the villages: Ampasilava, Tampolove and Andavadoaka (estimated populations 300, 500, and 2,200 respectively) were in the Velondriake Locally Managed Marine Area (LMMA). The Velondriake LMMA was established in 2006 and now includes 32 villages along a 45 km stretch of coastline. Velondriake operates in a co-management arrangement, governed by the Velondriake Association (VA), an elected association of community members, with support and technical backstopping provided by marine conservation NGO Blue Ventures. Initially, the LMMA operations were financed by ecotourism activities however in recent years this has been replaced by donor funding (Gardner et al., 2020). The VA manages temporary fishery closures, seven permanent no take zones and gear-based prohibitions (see Gardner et al., 2020 for further information on Velondriake). The fourth village, Ambatomilo (estimated population 700), was in the Manjaboake LMMA, directly south of Velondriake. Manjaboake was established in 2010. It is managed under a similar comanagement arrangement as Velondriake and includes temporary fishery closures and gear-based prohibitions. A permanent no- take zone was implemented in 2023 in Manjaboake LMMA, after the VOTV workshops (Blue Ventures, personal communication).

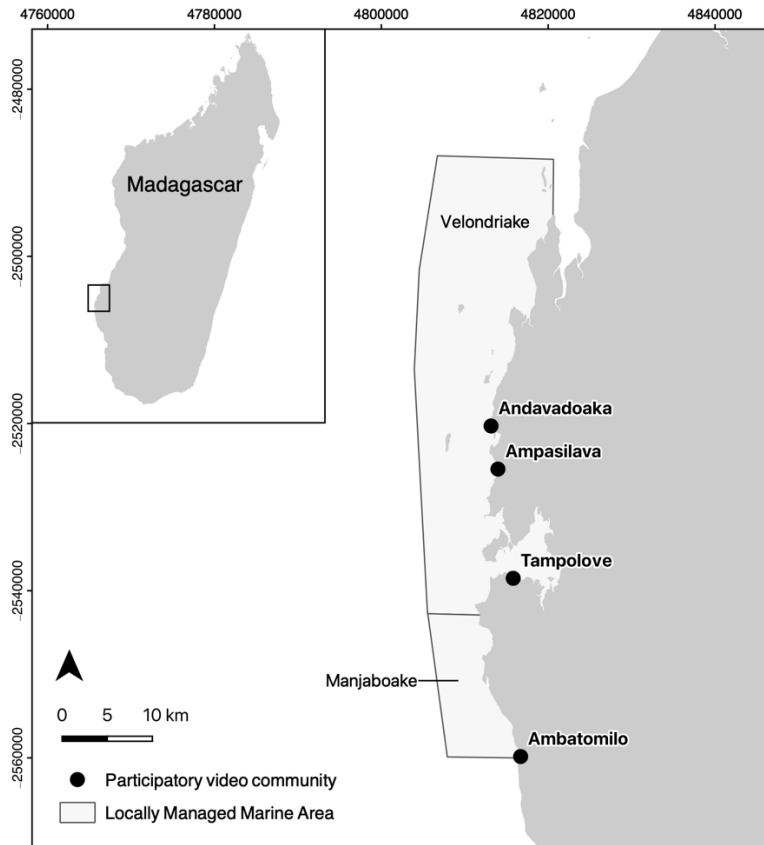


Figure 7.1 The location of the communities which took part in the Voices of the Vezo participatory video project and the boundaries of the locally managed marine areas in the region. Inset shows the location of the study region in southwest Madagascar.

7.3.3 Community Partnerships and Co-Production

Establishing trust between participatory video practitioners and the community is essential in participatory video projects (Harris, 2009; Wheeler, 2009). VOTV was undertaken in collaboration with the NGO Blue Ventures. Blue Ventures has been working in the southwest Madagascar since 2003 with a local headquarters in Andavadoaka employing around 25 residents. Blue Ventures maintained an uninterrupted presence has allowed it to become an enmeshed and active constituent within Velondriake, fostering trust and acceptance with the local communities. The partnership also provides the VA a vehicle to pursue legal procedure (e.g., ratification of local by-laws – the *dina*) and overcome social norms and dynamics (e.g., family ties, fear of retribution or witchcraft) which otherwise may prevent them from applying rules (a detailed assessment of the co-management partnership between the VA and BV can be found in Gardner et al. 2020)

The Blue Ventures Andavadoaka office has a dedicated outreach team responsible for building community connections and creating educational materials around health and environmental issues, often using film and radio. Blue Ventures' long-standing relationship with the communities was vital to the success of the project. The community members' familiarity with Blue Ventures and pre-existing level of trust was instrumental in obtaining permission for the PV workshops from the village chief (the *fokotany*) in each of the participating villages and finding participants willing to take part in the project.

The VOTV project team comprised both researchers and local employees of Blue Ventures and was co-led by authors A. Carter and S. Maniry Soa. The project was initiated by A. Carter following two years of social ecological research focused on the region. The idea was subsequently developed through a series of consultations with Blue Ventures staff including S. Maniry Soa, which involved refining research questions, selecting sites, and adapting the participatory video process to the local context. All participatory video workshop activities were conducted in the Vezo dialect and later translated into English.

7.3.4 Ethical Considerations

PV raises complex questions around confidentiality, data ownership and gaining consent from anybody filmed as part of the participatory process (Bali and Kofinas, 2014; Mistry et al., 2015). We endeavored to be adaptive and reflective in our approach in the context of different communities facing varying issues and challenges which may intersect the PV process (Mistry et al., 2015; Fisher et al., 2021).

In each village, the *fokotany* was approached and presented the project to get their consent. Each PV workshop started with a discussion of ethical issues with agreement that the participants would have access to the raw footage, own copies of the film and that all films would be available in the public domain. It was also emphasized to the participants that they were free to withdraw from the activity fully or partially at any time (Mistry et al., 2015). The ethical discussion was delivered verbally and confirmed with a signature from the participants. Before filming,

participants were trained in the importance of consent when conducting interviews, ensuring the interview subjects were fully aware of the project's goals and outcomes and of the public dissemination of the material (Bali and Kofinas, 2014). Participants were directed to obtain verbal consent for each interview.

The VOTV process was reviewed internationally (School of Geosciences, University of Edinburgh; Reference Number 2022-666) and in-country (Blue Ventures).

Institutional ethics guidelines do not exist in Madagascar; however, Blue Ventures has its own established ethics review process developed from a community ethics committee and two decades of experience working in the region. Blue Ventures has a Memorandum of Understanding with the VA that permits it to collate and share results related to the LMMA and an Accord de Siège with the Madagascar Government permitting it to carry out research.

7.3.5 Equipment

Filming was carried out exclusively with the iPhone 12 Max Pro using the application Filmic Pro. The choice of a smartphone was deliberate as, although technology access in the study region is generally low, a considerable number of community members own smartphones. This enabled the participants to quickly understand the camera controls due to their familiarity with the technology. The large size of the smartphone screen made it possible for all participants to view it simultaneously. In addition, each group was provided with a tripod and rig to hold the smartphone, a directional microphone with a windscreen, and a pair of over-ear headphones. Large paper and sticky notes were used during the group editing stage.

7.3.6 Participants

We refer to the youth that took part in the PV training and made the films as 'participants. In each village, six to eight participants (aged between 20 and 30) took part in the workshop. Those chosen to participate was determined by the leader of the local youth group and/or the village president. A total of thirty-one participants took part in the workshops, including eight men and 22 women. In the study region, youth group is a term used to describe a community group made up of the younger generation (around 30 and under) engaged in outreach and education activities

around community issues. All participants received an honorarium based on local norms as compensation for their time.

7.3.7 Participatory Video Workshop

We held a PV workshop in each of the four participating villages. The PV workshops took place over three to five days. Workshops included training the participants in camera and interview skills, recording footage for the film, footage reviews, group editing and feedback session where participants reflected on the PV activity.

Training and Filming

The workshops started with a brief overview of the project, which was followed by training in camera and interview techniques, facilitated through various games and role-play activities. Camera training commenced with basic instruction on camera and microphone controls, and subsequently focused on framing techniques (Figure 7.2A). Participants were also taught the role of 'B-roll' (cutaway footage) in providing visual interest and contextualization for the interviews. The camera equipment was deliberately handed over to the participants at the outset of the session to promote a sense of ownership of the project (Lunch and Lunch, 2006).

Prior to commencing the filming, the PV workshop facilitators engaged the participants in a discussion on the topic of marine ecosystem change and how this is impacting Vezo communities. While the VOTV team had an *a priori* interest in environmental change, the participants were encouraged to discuss any issues of interest to them within this topic. This approach helped support the participants to construct their own narrative on the issue, highlighting what they deemed important and interesting. To promote a comprehensive understanding of community perspectives and knowledge, we encouraged participants to interview different social groups in the community, including community elders, youth and an equal number of men and women. Interviewees were selected by the PV participants through a combination of targeted key informant interviews (for example, where the group identified a community leader, elder or resource user they wanted to include in the film) and opportunistic selection, as the group walked around the village.

For the filming in each village, the workshop participants were divided into two groups of four to five individuals and filmed for two days (Figure 7.2B). A facilitator provided support to each group during the initial interviews, assisting the participants whilst they became familiar with the equipment and filming techniques. During the two-day workshop, both groups met for regular footage review sessions. These sessions allowed the facilitators and participants to evaluate the footage and encourage peer-review within and between groups, promoting a sense of community ownership while also improving video and interviewing skills. Additionally, the facilitators utilized these sessions to identify areas where further training and guidance could enhance the quality of the videos and interviews.

Editing

The PV groups began the first stage of editing the films using a storyboard technique on a large sheet of paper (Figure 7.2C and D). Unlike editing on a computer, this approach allowed and encouraged the entire group to participate in the editing process without requiring knowledge of editing software. Through this technique, the PV participants determined the sequence of the interviews and selected the parts of the interviews that should be included in the film. They also determined which B-roll footage should accompany the interviews. The authors completed the final stage of editing by using the storyboards created by the participants as a guide to edit the films on a computer. Adobe Premier Pro software was used for all editing.

Workshop Feedback

After each workshop, we held a feedback session with the participants to gather their thoughts on their main learnings and takeaways from the PV process. The discussion was open-ended, with no strict format, and each participant was encouraged to share their opinion.

7.3.8 Translation and Analysis

We transcribed and translated 90 interviews that were filmed during the VOTV participatory video activities (including interviews that were not in the final edits of the films). The data collected through the interviews is substantial, however an extensive quantitative and qualitative analysis of the interviews go beyond the scope of this

paper. To provide context for our discussion, we present a synopsis of key themes in the interviews. We do not present a critical analysis of these themes with reference to existing literature. Our coding approach was to assign subject codes, similar codes were grouped into parent codes to identify key themes (Gibbs, 2007; Fisher et al., 2021). All analysis was undertaken in NVivo (Version 12, QSR International Pty Ltd).

7.3.9 Voices of the Vezo Outputs

During the four PV workshops, over 90 interviews were recorded. From the raw footage seven films of seven to fifteen minutes in length were produced (two films from each community except for Ampassilava where the participants requested to combine their footage into one film).

The outputs of the VOTV project included two phases. The initial phase was a debut community showing of the film which happened within two days of the PV workshops. In each village, the community showing was held in a public space on a large screen using a projector (Figure 7.3). Audience numbers were ~200 people in Tampolove and Ambatomilo, ~100 people in Ampassilava and ~50 people in Andavadoaka.

The second phase of the Voices of the Vezo included facilitating sharing of VOTV films with other Vezo communities, stakeholders and a wider audience. Films were subtitled in English and made publicly available on social media platform Facebook, YouTube and a dedicated website www.voicesofthevezo.org. Facebook was selected as it is the most popular social media platform in the study region. At the time of writing (September 2023), the films have combined views of over 400 times on YouTube and over 1000 engagements (likes, shares, comments) on Facebook.



Figure 7.2. Photos from the Voices of the Vezo participatory video workshops: (A) Camera and interview training with the workshop participants, (B) a participatory video group interviewing a fisher, (C) example of a storyboard created during group edit.



Figure 7.3. Creation of a temporary community cinema for the showing of the Voices of the Vezo participatory video film in Ampasilava.

Additional photos demonstrating the participatory video process are in Appendix 4.2.

7.4 Results

7.4.1 A synopsis of the Voices of the Vezo interviews

The interviews in the VOTV films document a wealth of local insights of marine ecosystem change and related consequences for the local social-ecological system. Table 7.1 presents a summary of codes and themes from the interview. Changes in the marine ecosystem and catch declines were a key theme discussed in nearly all the interviews undertaken for VOTV. Many people provided evidence for catch declines by comparing the weight of catches in the past and now. Fishermen reminisced at the ease of filling whole pirogues with fish on a single fishing trip, equivalent to catches of between 500kg to 1000kg, noting nowadays, this is rare. Women primarily discussed catch decline in the context of decreasing invertebrate catch, particularly octopus. A decrease in the biomass and species richness in the nearshore environment was emphasized by many community members. People explained how, in the past, it was possible to get a good catch close to the beach, but this is no longer possible. Due to the decline in the nearshore environment, fishers now travel further away to deep water to fish.

The drivers causing catch declines were another key theme throughout the VOTV interviews. The most referenced driver was the modernization and increase in the amount of fishing gear. Elders and adults spoke of the past only using lines and *hafotse* nets, made from the bark of a local tree species. Compared to the past, people now own more fishing materials including modern nets, spearguns and masks and fins. The destruction of coral during gleaning was the second most referenced driver for marine ecosystem change. Corals are broken to catch octopus that are hiding underneath them. People also discussed the occurrence of other destructive fishing techniques including poison fishing (*laro*) which is prohibited in the Velondriake and Manjaboake LMMAs. Prohibited activities were always discussed in general or as activities that others were responsible for, however individuals/ groups were not identified as being responsible. Some interviewees blamed the 'younger generation' for using destructive fishing techniques, such as breaking corals during gleaning. Increasing population was also identified as a driver for catch declines as

more people are fishing and gleaning. In the villages located in Velondriake, many community members attributed a decline in the marine resources to the increase in the number of children going fishing and gleaning. Community perception is that the age children start fishing has decreased in recent years. Children were not identified as a driver for catch declines in Ambatomilo. Less frequently mentioned drivers of change that were mentioned in the interviews included the creation of no-take zones preventing good catches, diving at night and the sound of boat engines disturbing marine life.

Many interviews included discussion of the social consequences of catch declines. Several community members expressed concerns for the future and the impact of declining marine resources on their livelihoods and food security. Some people discussed an eagerness to move away from a livelihood reliant on fishing or gleaning but recognized that there were few other opportunities. Community members in each village talked about how in the past Vezo were also farmers. Several attributed a decrease in rainfall over recent years to farming no longer being a viable livelihood. In Tampolove and Ambatomilo, seaweed farming was a key interview topic for women in the community. While seaweed farming was identified as an important source of income, several community members expressed concern about outbreaks of seaweed disease affecting production. In Tampolove, where there is a sea cucumber aquaculture site, sea cucumber farming was recognized as an important source of income. Improved education was recognized as a pathway to help people find alternative livelihoods.

Many of the interviews discussed the potential of different solutions to help better manage marine resources. Marine reserves were the most referenced solution, although it was not always clear if people were talking about temporary fishery reserves or no-take zones. In Ambatomilo, where there was no permanent no-take zone at the time of filming (November 2022), at least five people identified implementing a permanent reserve as a solution to improve the health of marine resources. In Andavadoaka, Ampasilava and Tampolove people expressed concerns about the rules of temporary fishery closures not being followed. In particular, they identified the theft of octopus during periods when the fishery is closed as a reason that octopus catch has declined during periods when the fishery is open. Stopping

the use of destructive fishing and gleaning techniques such as poison fishing, breaking corals and using small-size nets were also referenced as solutions to help sustainably manage marine resources.

Finally, several of the interviews included themes of culture and traditional beliefs. This included stories about the origin of each village and ceremonies including offerings to the ancestors and food sharing rituals. Some interviewees discussed taboo areas which would prevent people from accessing certain areas on land and in the sea. When discussing traditional ceremonies and beliefs, many individuals noted their decline in current times.

Table 7.1. Codes and parent codes emerging from interviews from four participatory video workshops in four villages in southwest Madagascar (Ambatomilo, Andavadoaka, Tapolove, Ampasilava)

Code	Parent Code
Decreasing marine resources; weight of catch; used to fish close to shore; species seen less/no longer seen; no catch/smaller catch; fished moved away/ moved deeper	Changing marine ecosystem/ fisheries
Improved fishing technology; increase in fishing gear; using destructive/prohibited fishing techniques; arrival of fish collectors; new generation catch more; increase in population; up to God; habitat destroyed; children starting fishing younger; small net mesh size; catching small fish; theft from reserves; creation of reserves; diving at night; sound of engines	Drivers of change
Life is difficult; go further/ deeper to fish and glean; not enough food; look for other livelihoods	Consequences of change
Seaweed farming; seaweed disease; sea cucumber aquaculture; agricultural farming; difficult to farm now (agricultural)	Alternative livelihoods
A reserve to recover fisheries; education; stop destructive fishing; alternative livelihoods; up to the new generation; reduce number of people fishing	Solutions
Less rain; seasons shifted	Climate/ weather
Origin of the village; fishing techniques of the past; traditional ceremonies/ rituals; sharing food; taboo areas	Traditions and history

7.4.2 Workshop Participants Feedback

The feedback sessions with participants revealed various themes related to the acquisition of knowledge and skills. The participants most frequently reported gaining new knowledge about the ancestral roots of their village, traditional fishing practices,

and the transformations that have occurred in the marine ecosystem over the previous generation.

As a Vezo, it is good to learn about this. We learned about the elders' stories and how the marine ecosystem was in the past, it is good to have knowledge of the past.

Participants acknowledged that the PV project had provided a platform for discussing community issues and sharing stories with elders. For example, one participant explained she enjoyed “learning about the stories of the past” and she was “happy to talk to people in the village”. The VOTV films were recognized by the participants as an effective way to gather and document marine ecosystem change and local knowledge in a way that is accessible to the wider community and future generations. Many participants expressed satisfaction in gaining new skills in filming and interviewing.

We have gained knowledge about the marine ecosystem we can share with our children and grandchildren.

In terms of feedback on the PV process, some participants expressed that they found it difficult to create questions for the interviews and would have welcomed more support from the facilitators at this part of the workshop.

7.5 Discussion

There are common challenges which arise within co-management arrangements in small-scale fishing communities, potentially undermining their ability to deliver desired social and ecological benefits. These challenges include lack of evidence concerning the social (Cinner et al., 2012) and ecological conditions (Granek and Brown, 2005; Fidler et al., 2021), the integration of local ecological knowledge in decision-making (Moller et al., 2004; Ullah et al., 2023), issues related to trust between local stakeholders and external organizations (Fargier et al., 2014), difficulty in fostering local participation and sense of ownership (Carr and Heyman, 2012) and the inability to influence external broad-scale forces which exert direct or indirect

pressure on the marine ecosystem (Granek and Brown, 2005; Long et al., 2019; Gardner et al., 2020). From the standpoint of local stakeholders, management partners and/or other collaborators, participatory video could provide a relatively low-cost and accessible means to help address these challenges, while directly engaging local community members (Bali and Kofinas, 2014; Bartindale et al., 2019; Mistry et al., 2021).

7.5.1 Participatory Video as a Tool for Co-management

Failures in the communication process can lead to tensions and adversarial relations between fishing communities and co-management stakeholders (Kaplan and McCay, 2004). Challenges emerge in how to communicate knowledge across different groups and synchronize different knowledge types such as local ecological knowledge and scientific assessments (Linke and Bruckmeier, 2015; Stefanoudis et al., 2021). Videography is a powerful tool to document community knowledge in traditional cultures as it aligns with approaches of storytelling for teaching and learning (Mistry et al., 2016a). In Vezo society, storytelling is an important method of passing knowledge between generations (Astuti, 1995). However, even in remote societies, technology is superseding oral traditions with digital culture reducing opportunities for knowledge transfer through oral traditions (Scroggie, 2009). In regions where literacy and a culture of written documentation is low, a decline in oral knowledge sharing risks the knowledge being permanently lost. Participatory video films provide an alternative audio-visual method of communication, knowledge transmission and documentation (Bali and Kofinas, 2014). For example, the VOTV films record stories of traditional beliefs and ceremonies which the interviewees identified as becoming less common. Furthermore, insights of historic ecosystem and social ecological conditions provide documentation of conditions during 2022 and may serve as evidence for future comparisons. Within the framework of co-management arrangements, PV films can be used for documentation and to communicate important issues between local resource users and co-management stakeholders. Beyond the co-management context, PV films can serve as educational resources, communicating local narratives that highlight the issues confronted by local communities.

The integration of local knowledge into co-management decisions can increase the legitimacy of local management decisions (Friedlander and Gaymer, 2021; Funk et al., 2022). This is particularly the case where official fisheries data are lacking (Ullah et al., 2023). In Madagascar, the status of fisheries is highly uncertain, demonstrated by the fact that catch reconstructions have been calculated as twice the volume reported by national fisheries agencies (Le Manach et al., 2012). However, the LEK of Vezo people of fish communities, species composition, seasonal trends and fishing grounds have been well documented by other authors (Astuti, 1995; Brenier et al., 2011; Langley, 2012; Lemahieu et al., 2018). PV can rapidly collect up-to-date LEK and share it widely with the community, offering a practical approach to gathering and assessing current social-ecological contexts while reflecting the community's current perspectives. Moreover, the community-driven process helps ensure the issues that are discussed in the PV films are likely to reflect the issues that community members consider most important. A benefit of recording this information through audio visual methods is that it can be directly shared back with the community creating a more transparent process for the implementation of management measures.

Co-management requires inclusive consultation processes that prevent management decisions that could further ostracize marginalized groups (Béné and Neiland, 2004). A key motivation for using participatory research methods is to encourage engagement from groups of society whose knowledge and viewpoints may otherwise be overlooked (Mistry et al., 2016b). The VOTV films included interviews with members of all cohorts of the community, including women and youth who, within the current co-management paradigms, remain more likely to be left out of decision-making spaces (Gardner et al., 2020). VOTV also engaged Vezo youth in making the films. The engagement and contribution of youth in small-scale fishery socio-ecological systems is often overlooked, despite making up a significant proportion of the workforce (Fry et al., 2021). In societies where decision-making is dominated by more affluent or experienced members of society, youth participation in decision-making is more likely to be obstructed (Kolding et al., 2014). Feedback from the VOTV youth participants included increased knowledge of the marine ecosystem, motivation to share this new knowledge and motivation to create films about other issues. The VOTV participant feedback indicates that PV, as several authors have

found, can be effective at building agency and empowering participants to make their voices heard (Christie et al., 2014; Tremblay and Jayme, 2015; Fisher et al., 2021).

The successful implementation of conservation measures and resource management commonly requires a shift of perception from local communities, particularly where reliance on resources is high. Through PV projects communities can be faced with narratives that challenge their own viewpoints which can encourage modified behaviors (High et al., 2012). For example, in a PV project in Malawi, farmers changed their perception of the value of composting and were encouraged to try new methods (Cai et al., 2019). Community perception in Velondriake is the principal determinant of spatial planning and resource management strategies (Gardner et al., 2020). Permanent reserves were determined by fishers' perception of the opportunity cost of excluding fishing in key fishing grounds (Cripps and Harris, 2009) and mangrove conservation was defined by willingness of community to set area aside for conservation (Rakotomahazo et al., 2019). In the VOTV films, the dominant interview themes which emerged (e.g., the impact of destructive fishing techniques and small mesh net sizes) indicate the success of awareness raising schemes undertaken by co-management partners, Blue Ventures. However, destructive fishing cited as a main driver of catch decline implies prohibited activities are still occurring. Community members referred to the implementation of reserves and stopping destructive fishing as methods to improve fish catches, potentially indicating a willingness to maintain or enhance management measures. In this light, PV provides the opportunity to systematize perceptions in a format accessible to the community, encouraging the mobilization of pre-existing knowledge and collective learning which could help change perceptions in the favor marine resource management (Tremblay and Jayme, 2015).

Finally, crucial pathways to establishing marine co-management include partnerships between the fishing communities and the partner organizations (government decision-makers, NGOs, universities). These partnerships must promote 'local champions' and nurture information sharing and trust (Domondon et al., 2021). Activities undertaken with natural resource users which incorporate trust-building can increase communication and willingness to adopt sustainable levels of use (Meinzen-Dick et al., 2018; Norström et al., 2020). In the months following VOTV, the

community in Ambatomilo voted to create the first no-take zone in the Manjaboake LMMA. Discussions about the creation of the no-take zone had started before VOTV, however local reports indicate that support shown for the creation of a no-take zone in the Ambatomilo VOTV films prompted action for its implementation (S. Maniry Soa, Pers Comm). Our research design does not allow us to infer causation or understand details of how VOTV may have influence local management decision in Ambatomilo. However, our findings align with observations from other authors that PV films could help prompt critical discussions which influence future policy (Christie et al., 2014).

7.5.2 Participatory Video: Practical Challenges and Considerations

PV is a dynamic research process that comes with practical and ethical challenges (Mistry et al., 2014; Fisher et al., 2021). A central motivation for researchers undertaking PV is to understand issues that are most important to the local community (Park, 2006). Therefore researchers/facilitators must provide enough instruction and guidance around the subject matter to enable the project while minimizing the introduction of external biases (Bartindale et al., 2019). During the VOTV project, we found it was a delicate balance between providing enough information for the participants to feel confident in the activities whilst not influencing the overall outcome. For example, while we provided training around the context and motivation of the films, we avoided suggesting explicit questions for the participants to ask during interviews. However, one participant expressed to the facilitators they struggled to formulate questions independently. Furthermore, filming is a technically challenging endeavour, particularly when outdoors. PV facilitators aimed to provide enough filming support to ensure there was usable material but avoid influencing the interviews. We observed that the presence of the facilitator would sometimes influence on the willingness of community members to give an interview. Some community members expressed they were eager to share stories with 'outsiders' while others seemed more reluctant to speak while the facilitators were present. To minimize causing bias in the interviews, facilitators only accompanied participants for the first one to two hours filming until they were more familiar with the equipment. After this, participants collected video material on their own with regular footage

reviews with the facilitators to identify filming or technical issues. We found issues could usually be addressed with a small amount of additional training or instruction.

Filmmaking in collaboration with communities is also time intensive. In VOTV, most of the workshop participants were women. This was not planned by the VOTV team and is likely because there is an expectation of men to go fishing (Barnes-Mauthe et al., 2013). On one hand, we recognize this as a positive outcome of the project in that it provided a training opportunity and platform for voices of a more marginalized group in Vezo society (Gardner et al., 2020). On the other hand, the films made by only women may not capture a broad range of perspectives of the community. The timing of the workshop and filming activities was also an important consideration to ensure the films represented balanced viewpoints. In Ambatomilo, we postponed the workshop as the original timing clashed with the local seaweed farm harvest. This clash would have excluded the women of the group from an entire morning of training which could potentially reinforce existing power dynamics.

PV has been used as a tool to present knowledge and perspectives of groups that are often underrepresented in decision-making (Milne, 2016). This rationale was discussed with VOTV workshop participants during the training phase. The VOTV facilitators encouraged the participants to endeavor to include members of all groups of the community in their films. This was achieved with varying levels of success with some of the films having a broader representation of community members than others. The issue of representation is likely to be a key challenge in any PV project with potential solutions differing depending on the local social and cultural context (Bartindale et al., 2019). PV will not erase power imbalances in the community; however, facilitators can have significant influence on reducing existing power differentials (Packard, 2008). Ongoing reflexivity at each stage of the process is required to recognize and respond to power imbalances and potential exclusion of marginalized voices (Pruitt, 2021). For example, during the training stage facilitators can work with participants to create a list of people in the community they plan to interview. The list could be based on social groups and therefore could provide the opportunity for the facilitators to work with the participants to consider the inclusion of groups that might otherwise be overlooked before the start of the filming.

Furthermore, a consideration in any PV project is the potential of conflicting interests or the inclusion or exclusion of sensitive material or viewpoints that could further exacerbate marginalization or power dynamic issues (Bartindale et al., 2019). In the VOTV films, a common theme of interviews was the occurrence of destructive fishing techniques indicating these prohibited activities are still occurring in the LMMA. This has been previously acknowledged by Gardner et al. (2020) who discuss the challenges BV and the VA have faced in successfully applying rules under the LMMA *dina*. We suggest that the framing of the VOTV films played a pivotal role in encouraging many community members to openly discuss the occurrence of prohibited activities. The films centered on the drivers of change in the marine ecosystem rather than focusing on the community members themselves, reducing the potential for blame or identification. Minimizing the potential of PV to have negative social consequences will be reliant on context as opposed to universal PV guidance (Pruitt, 2021). In this vein, partnership with facilitators who have a deep understanding of the community dynamics is essential.

Lastly, in this paper, our primary objective was to conduct a review and offer guidance on the process of PV where external parties are seeking to engage with communities. However, it is important to emphasize this process should be adapted to suit the needs of the local context. It is important to understand prior to the project where local groups may already be leveraging media as a means of local communication and education. For instance, in the same region as the Voices of the Vezo project, the second author, with other colleagues, has effectively utilized film and music as powerful tools for health education and the implementation of new marine management measures (Blue Ventures, 2022). This in-depth understanding of how video media is used within the local context offered invaluable insights when designing the VOTV process. Where there is the opportunity to do so, collaborating with local media experts will help ensure the process is relevant to local media engagement and culture and likely strengthen the overall impact of the project.

7.6 Conclusion

This paper has demonstrated the potential of participatory video as a tool in conservation co-management arrangements. A key and transferable finding is the

potential for PV to promote transparency and collective learning and empower marginalized groups in the stewardship of marine resources. Through synthesizing local perceptions and knowledge of complex social-ecological systems, PV can be used as a tool to support locally relevant marine management measures and document historical knowledge during times of rapid change. As conservation scientists and practitioners, we must continue to develop strategies that encompass the sharing of information and resources with local resource users and promote local leadership in the communities in which we work. Participatory video offers an excellent opportunity for an interdisciplinary and collaborative method of engagement in a conservation co-management context, supporting small-scale fishing communities and other natural resource dependent communities in their efforts to sustainably manage the natural resources on which they rely.

End of published manuscript

7.7 Chapter Afterword

In this chapter, I present the process and outputs of a “Voices of the Vezo”, a participatory video project carried out with coastal communities in southwest Madagascar, focused on ecosystem change and social-ecological issues. I examine participatory video’s potential as a tool for community co-management and outline practical challenges and recommendations for implementing a participatory video project. This chapter addresses Research Objective 3 by offering insights into an activity that can be effectively carried out within a co-management framework to support social and ecological outcomes. Furthermore, it contributes to Research Objective 4 by illustrating the application of participatory video as an exemplary method of knowledge co-production. This visual approach can facilitate the generation of robust social-ecological evidence, while supporting collective action and equitable decision-making in co-management scenarios.

7.8 Other Participatory Video Activities

Following the Voices of the Vezo project and the publication of this chapter in *Frontiers in Human Dynamics*, I replicated the participatory video methodology in three coastal communities in West Kalimantan, Indonesia: Mengkelang Jambu,

Seruat Dua and Dabong. This project, titled “Kisah Kubu Raya”—which translates to "Story of Kubu Raya" in Bahasa—was conducted in collaboration with the Indonesian NGO Planet Indonesia.

The objective of the films produced in this project differed from those in *Voices of the Vezo*. Rather than provide a predetermined topic for the films, in *Kisah Kubu Raya*, the community groups chose the subject of the films, addressing issues they identified as most prevalent in their communities. This approach resulted in three distinct participatory video films: one focused on agriculture and farming issues, another on promoting the conservation of a mangrove area linked to traditional beliefs and spirits, and a third on fishing activities and marine conservation. Like *Voices of the Vezo*, these films were subsequently shared with the participating communities at community cinema nights and have been used as educational and awareness-raising tools by Planet Indonesia.

As of May 2024, the impact of the films of *Kisah Kubu Raya* is still developing. Currently, the community of Seruat Dua, who focused on agricultural issues, plans to use their film as an advocacy tool to secure government support for training and tools in sustainable agriculture practices. Additionally, the film about fishing activities in Dabong has initiated discussions around current marine resource management measures (Josephine Crouch, Pers. Comm May 2024). The films will be available on [Planet Indonesia's YouTube channel](#) from June 2024.

7.9 Reference List

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Chapter 8: Discussion and Conclusion



Pirogues on the shoreline in Ambatomilo. Image: GCripps

8 Discussion and Conclusion

8.1 Key Findings and Novel Contributions

Facing the growing threat of global climate stressors and anthropogenic impacts on coral reefs, understanding the interdependencies between people and reef ecosystems is increasingly important for effective management (Berkes et al., 2009; Cinner et al., 2013; Barnes et al., 2019). In southwest Madagascar, where coastal communities have extremely high dependence on reef resources, the data-poor context in the face of rapid ecological change underscores the urgent need for increased social-ecological understanding. The research has focused on four overall research objectives.

1. Investigate social-ecological dynamics in response to climate and ecological change in small-scale fishing communities in Madagascar.
2. Analyse social dynamics of adaptive capacity and adaptation to climate and ecological change in reef-dependant small-scale fishing communities
3. Assess how co-management could influence social and ecological outcomes in the face of climate and ecological change.
4. Explore knowledge coproduction and participatory methods to create social-ecological evidence in data-poor regions.

Together the four research chapters have advanced understanding of social-ecological dynamics in the Velondriake Locally Managed Marine Area with wider application to reef-dependent communities throughout the coastal tropics. In the following section, I outline the key findings (Figure 8.1) and novel contributions of each research chapter.

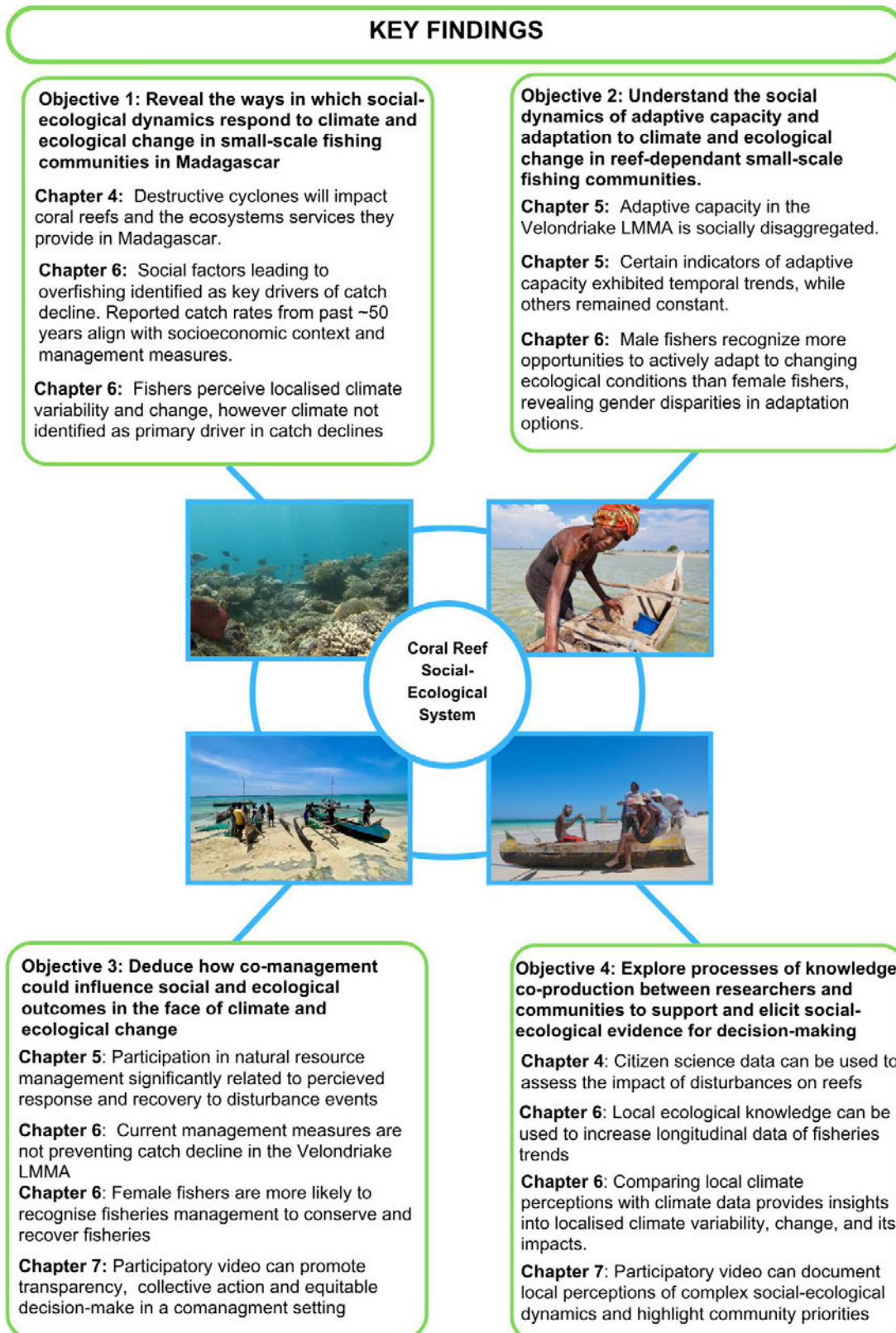


Figure 8.1 Key findings of the four research chapters in this thesis. Together the four research chapters have advanced our understanding of social-ecological dynamics in the Velondriake Locally Managed Marine Area. These findings have wider application to reef-dependent communities throughout the coastal tropics.

8.1.1 Chapter 4: Cyclone impacts on coral reef communities in southwest Madagascar

In **Chapter 4**, I found that Cyclone Haruna caused a heterogenic pattern of coral loss across reef sites and the coral composition to shift from dominantly complex branching morphologies to massive and encrusting. The severity of cyclone damage is related to distance from the cyclone track, duration of cyclone impact and reef depth. Two years after Cyclone Haruna, coral recruitment rates indicated positive signs of recovery. However, in a regime of increasingly frequent climate stressors, including more destructive cyclones (Tadross et al., 2008) and more marine heatwaves (Gudka et al., 2018), reefs are unlikely to return to a pre-disturbance state. Decreased coral cover and structural complexity will likely have a negative impact on the abundance of reef-associated organisms (Wilson et al., 2006) and the ecosystem's capacity to support local livelihoods and food security. While local management measures cannot prevent cyclone disturbances, they may reduce the likelihood of a catastrophic regime shift (McLeod et al., 2019). I made the recommendations to ensure the network of no-take zone areas in Velondriake covered diverse coral habitats and assemblages (Nyström et al., 2008). No-take zones support higher fish biomass (Gilchrist et al., 2020) thereby reducing the chance of a shift from coral to algal dominance following a disturbance due to a lack of herbivory (Hughes, 1994) and supporting coral recruitment and recovery (Graham et al., 2015). A review of recent literature demonstrates that community-based marine resource management can play a role in minimising immediate social impacts of natural disasters such as cyclones. For example, through social collaboration, implementation of alternative livelihood projects and the adoption of adaptive management strategies to reduce the impact on food security and income. Recognizing the social value of community-based fisheries management in the face of natural hazards adds another imperative for local communities, partnering institutions and policymakers to strengthen and support management measures.

Chapter 4 also contributes to the global geographic evidence of cyclone impacts on reefs presenting the first assessment of the impact of a cyclone on a coral reef ecosystem in Madagascar and one of the few undertaken in the Western Indian Ocean. It also represents the first published study of cyclone impact on coral reefs using citizen science reef monitoring data. Given the increasing frequency of large-

scale coral degradation, the provision of actionable monitoring data is imperative (Obura et al., 2019). My results demonstrate the potential of citizen science monitoring data to provide scientifically robust evidence of reef ecosystem changes, particularly in data-scarce and economically constrained regions. As tightly coupled coral reef social-ecological systems often occur within such contexts, my findings underscore the potential of citizen science to contribute to actionable monitoring data to help inform local management.

8.1.2 Chapter 5: Adaptive capacity of small-scale fishing communities in the face of diverse disturbances

In **Chapter 5**, I investigate the social and temporal dynamics of adaptive capacity in Velondriake using social surveys undertaken in 2016 and again in 2021 to address three key knowledge gaps in the adaptive capacity of small-scale fishing communities. I find adaptive capacity in Velondriake is differentiated between different groups. Key findings include women exhibiting lower scores in social capital indicators, the older age group scoring lower in the wealth and assets domain, and men recording lower scores in the flexibility domain. Most adaptive capacity studies in SSF communities are undertaken at the household or community level, yet adaptive capacity has been shown to be socially disaggregated. Thus, the disaggregated analysis provides insights for targeted interventions that facilitate adaptation.

Secondly, I investigated changes in adaptive capacity through time (between 2016 and 2021). I find that some indicators stayed stable between 2016 and 2021, while others showed significant change. Considering COVID-19 which occurred between 2019 and 2020 and had a significant socioeconomic impact on coastal communities in Madagascar, the stability of wealth and asset indicators suggest the Velondriake community recovered from the disturbance of COVID-19 in a relatively short time frame. Most assessments of adaptive capacity are static, yet adaptation processes are inherently dynamic. Therefore, temporal analysis can help assess how adaptive capacity is responding to external changes.

Finally, I empirically test the adaptive capacity indicators' relationship to resilience and recovery to disturbance events. I found that high adaptive capacity scores did

not consistently lead to improved response or recovery outcomes to disturbance events. Further, I observed distinctions in adaptive capacity indicators associated with chronic and acute disturbance events. My results underscore the need for caution when using theoretical adaptive capacity indicators as proxies for understanding the vulnerability of coastal communities to disturbance events. Much of the existing adaptive capacity literature relies on theoretically informed indicators. The approach taken in this thesis contributes to empirical evidence of how adaptive capacity translates into resilience and recovery in the face of real-world disturbances.

8.1.3 Chapter 6: Integrating fishers' knowledge to investigate social-ecological dynamics and climate change in small-scale fisheries in Madagascar

In **Chapter 6**, I focus on improving understanding of ecosystem trends and localised climate impacts in Velondriake – both key knowledge gaps that have been identified as barriers in fisheries management in SSF communities globally (Allison and Bassett, 2015; Martins and Gasalla, 2018; Pita et al., 2019; Castello et al., 2023). In southwest Madagascar there are isolated studies that report catch rates since the 1950s however these lack consistency in location and assessment methodology. I integrate local ecological knowledge with statistical modelling to create a continuous timeline of catch rates of fin fish and octopus in Velondriake over the past ~50 years. Fisher's perceptions indicate that both fisheries began to decline in the 1990s. I find a pattern in catch per unit effort that may align with population dynamics driven by socio-economic and management context, e.g. the arrival of international seafood export companies and temporary fishery closures. My findings add to the growing body of evidence of overfishing in small-scale fisheries in Madagascar (Gough et al., 2020, 2022).

In this chapter, I also include qualitative historical accounts of ecosystem change from Vezo elders. Along with declining catches, the predominant themes in these accounts were the depletion of nearshore ecosystems and in particular large marine organisms such as shark species. Given the lack of historic data on fisheries and nearshore ecosystem in Velondriake, fisher's qualitative and quantitative accounts provide crucial evidence to help inform marine management in the region.

Limited research exists that offers empirical evidence on the social impacts of current and recent climate variability and change within small-scale fishing communities in Madagascar. Further, local observational climate data is sparse and incomplete. To address this gap, in **Chapter 6** I gathered fishers' perceptions of climate and the impact it had on their daily lives. I found that reports from fishers of trends in localised temperature, wind speed, wind direction and precipitation largely aligned with climate reanalysis data (created through blending observational data with climate models). An increase in unfavourable wind conditions for fishing was the most frequently cited climate impact, likely because wind has the potential to disrupt fishing efforts and increase physical risks to equipment and individuals (Heck et al., 2021). My findings demonstrate how fisher's knowledge of localised climate impacts could be used as evidence to develop targeted and effective responses to climate change and adapt to changing conditions (Villasante et al., 2022).

Finally, in **Chapter 6** we investigate community perceptions and responses to environmental and climate pressures, thereby contextualising findings of ecosystem and climate change within the social-ecological context (Nematchoua et al., 2018). Declining catches were attributed primarily to an increased number of fishers, intensified fishing effort, changes in fishing gear and destructive fishing practices. In the context of adapting fishing methods and behaviours in response to shifting ecological conditions, men reported several methods of adaptation while most women reported making no changes. Women were more likely to suggest enhanced fishery management options to support fisheries recovery. However, barriers to inclusive governance and decision-making (highlighted in Chapter 4) could hinder the ability of female fishers to drive change.

8.1.4 Chapter 7: Participatory video as a tool for co-management in coastal communities: a case study from Madagascar

Chapter 7 outlines the process and results of a project using a visual research method, participatory video, to document and disseminate local knowledge of shifting social and ecological conditions. Participatory video is a practical methodology which fosters knowledge coproduction with local resource users. Coproduction of knowledge has been identified as a priority to improve the social benefits of ocean

sustainability projects (Mastrángelo et al., 2019; Macher et al., 2021; Partelow et al., 2023). This study represents a novel exploration and evaluation of using participatory video to support co-management activities in a coastal community setting. Four communities participated in the project with 90 people interviewed and seven short films (7–15 min) created. I found videography to be a powerful tool for producing and documenting knowledge of shifting social and ecological conditions, especially where written records are scarce. The dominant themes discussed in the interviews undertaken for the films broadly echoed findings in Chapters 4 and 5 regarding climate, ecosystem change, and social impacts. Additionally, the interviews included themes of tradition and culture related to fishing activities which were absent in other research chapters. This provides a demonstration of where knowledge co-production can compensate scientific methods which may struggle to capture cultural complexity and context (Norström et al., 2020). The films were shared in the participating communities at public cinema nights in the study region and made available online. A key and transferable finding from **Chapter 7** is the potential for participatory video to promote transparency and collective learning and empower marginalised groups in stewardship of marine resources. When preparing for the research activities for **Chapter 7**, I found there was a gap in the literature around practical considerations of undertaking participatory video in a research context. Therefore, I also presented a detailed discussion of the practical challenges and considerations encountered during the participatory video project, including the identification of potential sources of bias. This is with the ambition that other researchers and/or practitioners will find this useful when conducting their own participatory video projects.

8.2 Cross-Cutting Themes and Future Research

Themes emerged throughout this thesis which hold relevance for social-ecological research and implications for natural resource management in Madagascar and small-scale fishing communities across the global tropics. In this section, I discuss these themes and contextualise them in existing knowledge. I also discuss their implications across different scales of management and highlight avenues for future research.

8.2.1 Management and Governance Across Spatial and Temporal Scales

A key objective of this research was to investigate how co-management can confer social-ecological resilience within reef-dependent communities. While I place my findings in the context of co-management throughout the chapters, my findings also make it evident that local measures operate within a setting of global socioeconomic forces and climate change drivers. Furthermore, my investigation predominantly centres on resilience in the current context, however social-ecological change under future climate scenarios might potentially diminish the relevance of the strategies proposed. In the following section, I discuss opportunities for local management but also contextualise my research in the context of global drivers and future climate change. I base my discussion on Madagascar, yet its relevance extends to reef-dependent communities globally, particularly in East Africa, where coastal communities share similar sociocultural contexts and coral reef assemblages (Rocliffe et al., 2014; Obura et al., 2017)

Local (co)management for ecological resilience

Local management measures to support and maintain reef ecosystem services are critical for the food security and livelihoods of reef-dependent communities (Darling et al., 2019; Eddy et al., 2021). My research findings of the impact of a cyclone on the reef ecosystem, coupled with evidence of overfishing, suggest that the increasing frequency of destructive cyclones concurrent with the increasing frequency of marine heatwaves will threaten the resilience of coral reefs in Velondriake (Obura et al., 2017). While protection from local management measures are unlikely to directly increase coral resilience to global climate stressors (Bruno et al., 2019), recent findings from Madagascar (Randrianarivo et al., 2023) and the wider Indo-Pacific (Darling et al., 2019) demonstrate that managed sites are often associated with increased coral diversity and cover. For example, in northwestern Madagascar, a positive relationship was found between high fish biomass in protected areas and coral cover (Randrianarivo et al., 2023). However, this relationship was not observed at all protected sites and likewise, Gilchrist et al., (2020) found this association to be absent from no-take zones in Velondriake. Age is a major factor in the effectiveness of managed areas and I hypothesise that the relatively recent establishment of no-

take zones in Velondriake (established between 2009 and 2014) may explain the apparent absence of positive effects on coral cover (Selig and Bruno, 2010; Friedlander et al., 2017). This underscores the importance of long-term protection and monitoring to evaluate the effectiveness of management measures (Vandeperre et al., 2011; Friedlander et al., 2017).

Additionally, size, depth and connectivity are also major factors in MPA effectiveness (Friedlander et al., 2017; Ferreira et al., 2022). Extending the no-take zones in Velondriake to account for a diverse range of reef environments, encompassing different morphologies and species, may help mitigate the impact of uncertainty in the pattern of damage caused by future cyclones and may support recruitment and connectivity with other regions (Ateweberhan and McClanahan, 2016). Protecting these areas against activities that will decrease rugosity (e.g. destructive fishing gear) is key to maintaining ecosystem services provided by reefs (Darling et al., 2017). This thesis has demonstrated the detailed local ecological knowledge of Vezo fishers. Integrating this knowledge for the identification of important reef areas, engaging resource users in monitoring efforts and increasing community awareness around the function of corals may help support sustainable management outcomes (McClanahan et al., 2014).

This thesis contributes to the substantial recent evidence of the occurrence of overfishing in the small-scale fisheries on the west coast of Madagascar (Gough et al., 2020, 2022; Ranaivomanana et al., 2023), indicating that local management measures are currently not adequate. Marine reserves in Velondriake have been shown to have higher fish biomass than non-protected regions (Gilchrist et al., 2020). This suggests there is potential for them to help sustain local fisheries via spillover (the outward migration of fish from the protected area; Di Lorenzo et al., 2020). However, fisher reports of a decrease in average fish size (Chapter 6) align with recent studies that find a majority of fish landed by SSF in west Madagascar have not yet reached maturity (Gough et al., 2020; Ranaivomanana et al., 2023). This reduces the likelihood of spawning and subsequent marine resource renewal which has major ecological and socioeconomic implications (Pauly et al., 2005). Sized-based fishery restrictions are an additional management approach not currently implemented on Velondriake that can support sustainable fisheries

management in data-poor fisheries (Prince and Hordyk, 2018). This could be implemented by introducing minimum mesh sizes and phasing out non-selective fishing gears (McClanahan et al., 2014; Rocliffe et al., 2014). However, such restrictions will inevitably have impacts on local livelihoods and food security (Ranaivomanana et al., 2023), thus the implications of measures will need to be carefully considered and accounted for. In co-management arrangements, providing capacity-building for participatory monitoring of fish size could help close vital knowledge gaps about the status of reef fisheries in west Madagascar, while also supporting fishers to adopt more sustainable fishing practices (Prince and Hordyk, 2018; House et al., 2023).

National and International Governance

Solutions for the governance of social-ecological systems require working across multiple scales (Berkes, 2006; Nayak and Berkes, 2014; Bellwood et al., 2019). While the research in this thesis was primarily focused on a local scale, findings consistently reveal connections between national and global-scale drivers and local social-ecological change. For instance, Chapter 4 demonstrates the impact of an intense tropical cyclone on the local coral reef ecosystems. Chapter 6 indicates that the declining catch trends of small-scale fishers align with the introduction of commercial fisheries exploitation for export. Finally, Chapter 5 highlights the localised impacts of COVID-19 on the livelihoods of coastal fishers, influenced by disruptions in the global seafood supply chain. Discussions on the governance of climate change at the national and international level are well developed with discourse centred on the imperative for countries to reduce carbon emissions to mitigate the impacts of climate change (UNFCCC, 2023). Contributing additional novel insights into this discussion goes beyond the scope of this thesis. However, I have found significant knowledge gaps and lack of discourse regarding the relationship between local resource management and national and international scale governance of small-scale fisheries market chains. Thus, this will be the focus of the following discussion.

As small-scale reef fisheries are becoming increasingly coupled with global market drivers, local management alone becomes insufficient (Bellwood et al., 2019). For example, demand-driven consumer markets in China have intensified exploitation

through large parts of the tropics (Eriksson et al., 2015). Where there are weaker laws or corruption, market mechanisms are often a strong determinant of fishing patterns (Steenbergen et al., 2019). Given that a majority of coral reefs and reef fishers are located in low-income countries (González-Espinosa et al., 2023) where these institutional challenges are more prevalent (Montinola and Jackman, 2002), it presents a challenge for the sustainable management of reef resources. Like many tropical developing countries, Madagascar's state lacks the capacity to regulate its fisheries sector effectively. The post-harvest value chain is managed exclusively by commercial actors who show little incentive to reward fishers for their fisheries management efforts, despite it being in the best interest of the value chain actors (Gardner et al., 2017). Meanwhile, widespread poverty and low literacy levels among the fishers mean they remain vulnerable to exploitation and unfair distribution of benefits (Barnes-Mauthe et al., 2013). Improvement of state-led capacity would require substantial investment, however, the investment would be modest relative to the importance of SSF for both poverty alleviation and food security (Harris, 2011; Gardner et al., 2017). I identified two key aspects of institutional capacity in Madagascar where improvement is critical to support sustainable management of small-scale fisheries exports.

First, the lack of monitoring data, which is necessary to make informed decisions about sustainable resource use (Pita et al., 2019; Gough et al., 2020), and maintains the low visibility of SSF in national policies (Cohen et al., 2019). The research in this thesis contributes to increasing evidence of the depletion of nearshore ecosystems in southwest Madagascar, highlighting the urgent need for comprehensive monitoring to make informed decisions about fisheries management. This data will be essential for effective and targeted management at the community level.

However, a framework to enable the incorporation of fisheries data at a regional and national scale will allow for the identification of larger trends and patterns.

Understanding these overarching dynamics is critical for formulating informed national-level SSF policies. For example, the creation of export quotas which are guided by principles of food security (McClanahan et al., 2015) and the introduction of minimum catch size and harvest control legislation (Gough et al., 2020). Non-governmental actors will likely remain at the forefront of fishery improvement efforts

in Madagascar, however, the state and private sector have a crucial role in scaling these initiatives and enshrining them in policy (Gardner et al., 2017).

A second critical challenge for improving national-level capacity for sustainable fisheries management is the knowledge gap concerning the contribution of SSF to national GDP, poverty reduction and food security (Le Manach et al., 2012; March and Failler, 2022). Since policy decisions are influenced by economic considerations, recognising the socioeconomic value of SSF becomes pivotal in national-level support for sustainable management (Ayilu et al., 2022). Increased understanding of their socioeconomic importance may create motives for national-level policies to support the rights of small-scale fishers, for example, to ensure they are not in direct competition with foreign industrial fleets (White et al., 2021). Moreover, recognition of the multifaceted socioeconomic contributions of SSF underscores their importance in achieving international targets such as the Sustainable Development Goals. This recognition may potentially garner support from international development actors and the private sector for sustainable fisheries management (Dahlmann et al., 2019; Said and Chuenpagdee, 2019) and encourage targeted research support.

Planning for Future Climate Scenarios

The scientific consensus underscores that global climate change is expected to amplify in the coming decades (Change, 2023). In Madagascar, temperature is expected to increase by 2°C from historic levels (1950 – 2005) by 2030, accompanied by a potential 3% decrease in rainfall in some regions (Nematchoua et al., 2018). These changes pose serious implications for crop production, potentially escalating reliance on marine resources as observed in the coastal migration of inland communities following agricultural failure (Le Manach et al., 2012). Simultaneously, driven by ocean warming, acidification and sea-level rise, the maximum potential yield of fish is predicted to decrease by 15% to 30% on the west coast of Madagascar (Lam et al., 2020). Furthermore, based on ecosystem indicators and sea surface temperature projections the coral ecoregion of west Madagascar has been identified as vulnerable to collapse in the next 50 years (Obura et al., 2022). Ecosystem collapse signifies the absence of key biota and interactions characteristic of a coral reef, implying a significant reduction in reef

ecosystem services (Woodhead et al., 2019; Eddy et al., 2021) and significant implications for the food security and livelihoods of Vezo people.

Despite our increasing understanding of future climate scenarios, the lack of information about localised weather, climate and climate impacts provides a significant obstacle to effectively planning local interventions (Weiskopf et al., 2021). The chapters of this thesis contribute to evidence of current and recent climate impacts on coral reefs and coastal communities in southwest Madagascar. This includes the destructive potential of tropical cyclones on local reefs (Chapter 4), the identification of adaptive capacity indicators in the face of chronic climate disturbances (Chapter 5), validation of modelled climate data through local insights (Chapter 6), and a nuanced exploration of how climate change impacts materialise in the lives of the Vezo people (Chapter 6 and 7). However, as outlined above, future climate scenarios will likely push the social-ecological system into uncharted territory. These changes will surpass the current experience of climate shocks and disturbances, exceeding critical thresholds that necessitate a paradigm shift in resilience planning. For instance, supporting food security for coastal livelihoods in Madagascar amidst increasing demand on marine resources and the collapse of coral reef ecosystems demands a thorough reassessment of the trade-offs between the economic value of the fisheries export market and the imperative need for local food security. In preparing for these challenges, it is imperative to integrate our current understanding of recent and ongoing socioecological resilience and system dynamics within the framework of future climate scenarios. Making this integration a key research priority is crucial for informed decision-making, ensuring that interventions today do not steer communities towards investing all their efforts and resources into short-term solutions that may prove unsustainable in the coming decades.

8.2.2 Opportunities for Adaptive Capacity

Adaptive Capacity and Social-Ecological Research

As demonstrated in this thesis, reef-dependent small-scale fishing communities are confronting various stressors stemming from environmental, social, and economic changes. To minimise negative impact, a priority is to build adaptive capacity to existing and anticipated stressors (Cinner et al., 2018; D'agata et al., 2020; Ilosvay et

al., 2022). Despite Africa's coastal regions being identified as some of the world's most sensitive and vulnerable to climate change (Trisos et al., 2022), studies of social-ecological resilience and adaptive capacity remain underrepresented (Ferro-Azcona et al., 2019). Furthermore, a majority of these studies occur at community or household scale (McClanahan et al., 2008; Cinner et al., 2012a, 2013). In Chapters 5 and 6, I find that adaptation options and adaptive capacity in Velondriake is differentiated between social groups. These findings align with the view that caution is required when undertaking aggregated analyses of adaptive capacity indicators as it could overlook social dynamics critical to ensure interventions are effective (Adger and Vincent, 2005; Vincent, 2007). Furthermore, we provide evidence that high scores of adaptive capacity indicators do not always translate to reduced impact or better recovery from actual disturbance events. These findings underscore the need for further work to empirically test the relationship between adaptive capacity indicators and adaptive behaviour (Cinner et al., 2015; Ferro-Azcona et al., 2019).

Adaptive Capacity and Local Management

There is growing recognition of the social impacts of community-based management and its potential to confer adaptive capacity in coastal communities in the face of environmental and climate change (Cinner et al., 2012b; Marin et al., 2015; Pike et al., 2022). However, there are underlying knowledge gaps and complexities that may limit its effectiveness in doing so. First, there is little evidence positively associating improved ecosystem health related to community-based management with adaptive capacity. In fact, D'agata et al., 2020 found across 29 SSF communities in the Western Indian Ocean, a majority of communities had an inverse relationship between ecological conditions and social adaptive capacity. However, local marine management in the WIO is associated with higher fish biomass indicating its potential for supporting food security and income in SSF communities (D'agata et al., 2020; Randrianarivo et al., 2023), particularly those with extremely high dependence on reef resources. This could be particularly significant in the face of climate or socioeconomic shocks that disturb market access (Chapter 5; Eriksson et al., 2017).

A further limitation for community-based management to support adaptive capacity lies in varying degrees of social capital around marine resource governance (Baker-

Médard et al., 2023). The dynamics of social capital within a community can influence the effectiveness of governance structures and the extent to which individuals are included in decision-making processes. This variation in social capital can result in inequitable involvement in governance activities, potentially leading to unequal access to resources and exacerbating existing socioeconomic disparities (Ruano-Chamorro et al., 2023). Additionally, marginalized groups may face challenges in having their specific needs fully recognized within the governance framework. For instance, in the context of Velondriake, female fishers may urgently require livelihood diversification strategies due to a decline in octopus catch and limited adaptation options (Chapter 6). Factors such as income, age, and migration status (migrants vs. non-migrants) may also influence the specific needs essential for enhancing adaptive capacity (Chapter 5; Cinner et al., 2015). In light of these considerations, the development of co-management interventions for adaptive capacity must include a careful examination of equity issues (Bennett et al., 2021). It is crucial to ensure that decision-making processes and resource allocations are fair and consider the diverse needs of community members. These findings align with the broader calls for "adaptation science" (Hidalgo et al., 2022), emphasizing an integrated approach that combines socio-economic, ecological, and policy-governance perspectives. This holistic approach is essential for generating evidence-based knowledge necessary to guide interventions in co-management settings, fostering adaptive capacity while promoting social equity within small-scale fisheries.

Gender Dynamics of Adaptive Capacity

Gender equality has been recognised as a global priority in the pursuit of social equity and the sustainable management of small-scale fisheries (FAO, 2015). Moreover, gender has been found as a key determinant of adaptive capacity in coastal communities (D'agata et al., 2020; Pike et al., 2022). Nevertheless, significant knowledge gaps remain about the gendered differences in adaptation to environmental and climate change (Cinner et al., 2018; Murunga, 2021). My findings further demonstrate gendered dimensions of adaptive capacity in SSF communities. Viewed together, my research suggests that female fishers in Velondriake are currently most vulnerable to declining fisheries yet are willing to adopt adaptation

options including alternative livelihoods and natural resource management measures. However, where women have lower social capital, wealth and assets, power dynamics may hinder these positive adaptation pathways from being realised. This is consistent with the findings indicating that gendered power dynamics in SSF governance present a significant barrier to gender equality within small-scale fishing communities in the West Indian Ocean (Carmen et al. 2022), consequently affecting the adaptive capacity of women (Cinner et al., 2012a, 2015)

Despite a substantial body of evidence on the gendered dimensions of SSF, there is limited scholarly understanding of gendered power relations and how to meaningfully engage women in SSF governance (Kleiber et al., 2017; Galappaththi et al., 2022). Since 2020, Madagascar already has in place a Fisherwomen Leadership Program, a network formed in recognition of the gender inequities occurring in the management of the country's LMMAs (Baker-Médard et al., 2023). Investigating how this group influences power structures and participation in the years ahead presents a valuable opportunity to address a critical knowledge gap in equitable decision-making and power dynamics in the context of SSF governance with relevance well beyond Madagascar (Galappaththi et al., 2022). For example, a community forestry organisation formed around previously disaggregated women's groups improved the engagement of women in resource management and stewardship (Arora-Jonsson, 2012). For the advancement of gender equality and effectiveness of adaptation policy, future social-ecological research requires critical gender analysis, acknowledging power dynamics and the uneven impact of climate and environmental change (Kleiber et al., 2015; Cohen et al., 2016; Kawarazuka et al., 2017; Andrijevic et al., 2020; Murunga, 2021). This will not only make progress in the field of social-ecological research but also generate better evidence for decision-makers in the face of environmental and climate change.

8.2.3 Integration of Diverse Knowledge Types

Local Knowledge in Data-Poor Regions

Integrating local ecological knowledge and participatory research methods will be required to address knowledge gaps around rapidly evolving and dynamic social-ecological systems (Mastrángelo et al., 2019). Research in this thesis contributes to addressing the knowledge gap on how researchers can integrate Western scientific

methods and local knowledge to investigate temporal changes in marine social-ecological systems. For example, Chapter 6 provides an example of a straightforward and easily replicable method of asking respondents about their perception of changes throughout their lifetime (McCarter and Gavin, 2014; Aswani et al., 2015). Despite uncertainties, this approach yields crucial insights, offering a long-term perspective of fisheries trends that are otherwise not available for small-scale fisheries in southwest Madagascar. This underscores how adopting local ecological knowledge to increase longitudinal data, together with participatory monitoring and scientific methods, can create a more comprehensive and informed foundation for management strategies (Leduc et al., 2021; Castillo-Morales et al., 2023).

Chapter 5 provides novel evidence about localised impacts of climate change on small-scale fishing communities in Madagascar. Utilising local knowledge to understand climate change impacts has been less explored compared to its application to understand ecological changes (Ruiz-Mallén and Corbera, 2013; Ford et al., 2016; Zvobgo et al., 2022). Yet, relying on large-scale climate assessments for formulating climate-related policies underestimates socio-economic risk (Rising et al., 2022) and may inadvertently homogenize knowledge, culture and ways of understanding climate change, leading to misguided adaptation strategies (Ford et al., 2016). Thus, grounding climate records and climate projections in local experience is vital for locally relevant and culturally appropriate policies (Marschütz et al., 2020). In the context of co-management, gathering narratives of climate change impact at the local level can help understand how climate change is conceptualised in the region and thus inform strategic planning and effective resource allocation in adaptation planning (Zhang and Bakar, 2017).

Gender Dimensions of Local Ecological Knowledge

Gender equality and women's participation are recognised as important parts of small-scale fisheries management (FAO, 2020). In gender-specific fisheries, women have distinct ecological knowledge which provides important information for marine resource management (Harper et al., 2013, 2020). Nevertheless, knowledge gaps remain about women's contribution to fisheries management (House et al., 2023)

and research methods still perpetuate bias that overlooks women's distinctive local ecological knowledge (Kawarazuka et al., 2017). Chapters 6 and 7 demonstrate the disparate ecological knowledge held by male and female fishers in southwest Madagascar, highlighting their distinct knowledge of fisheries (finfish vs invertebrate) in different parts of the coastal environment (intertidal vs subtidal). Despite recognition of the critical role women play in small-scale fisheries in Madagascar (Westerman and Benbow, 2013), these findings represent novel evidence of female-specific local ecological knowledge of nearshore fisheries change. My results reinforce views that there is an opportunity for gender analysis in SSF to move beyond social domains of resilience and engage directly with questions of ecology to generate more informed evidence for decision-making (Harper et al., 2013; Kawarazuka et al., 2017; Thomas et al., 2021). Furthermore, it reinforces the case for prioritising female participation in decision-making to make more informed decisions in fisheries planning and management in nearshore ecosystems (Solano et al., 2021; Kitolelei et al., 2022). These findings are relevant in coastal small-scale fisheries throughout the global tropics where a majority of fisherwomen predominantly operate in the intertidal zone (Harper et al., 2013, 2017).

Knowledge Coproduction for Transformative Governance

Knowledge coproduction rejects the notion that scientists alone identify problems and deliver knowledge to society. Instead, it advocates for interactive collaborations between academic and non-academic partners (Norström et al., 2020) and provides a pathway for the decolonisation of marine conservation science through prioritisation of community concerns (Spalding et al., 2023). In the context of community-based management, addressing the knowledge-action gap - whereby knowledge is ignored or dismissed by knowledge users (Cvitanovic et al., 2015) – requires a commitment to coproduction methods. The process of coproducing knowledge is inevitably complex as it often involves navigating situations with divergent worldviews and power inequalities (Caniglia et al., 2023). Throughout this thesis, coproducing knowledge demanded reflexivity and close collaboration with local partners, especially in the development of research methods and questions. Chapter 7 discusses the ethical and practical considerations when undertaking knowledge coproduction in the context of participatory video. I reflect on the

importance of local collaboration, consideration of power dynamics and the potential introduction of bias in the co-production process. These considerations are relevant across coproduction methodologies (Brook and McLachlan, 2008; Gerlak et al., 2023). Despite challenges, we found participatory video to provide detailed insights into social-ecological changes while also promoting community awareness, education, and empowerment on marine conservation issues. It effectively responds to the UN Ocean Decade's call to communicate research findings “in forms that are widely understood and trigger excitement”. This observation aligns with the increasing acceptance of art-based methods to enable transformative ocean governance. Such methods serve as valuable tools for incorporating local knowledge and gaining a nuanced understanding of power dynamics and tensions (Norström et al. 2020).

8.3 Conclusion

Understanding complexity in social-ecological systems is identified as a top research priority to help deliver global sustainability goals (Mastrángelo et al., 2019) and is critical for environmental problem-solving in reef-dependent communities (Barnes et al., 2019;). This thesis provides novel insights into social-ecological dynamics in a small-scale fishing community in southwest Madagascar. The findings provide evidence for ecological trends, social and ecological impact of climate variability, climate change and other disturbances and the social dynamics of adaptation and resilience. Together, the research underscores how rapid ecological change driven by multiscale social and climate drivers threatens the livelihoods of small-scale fishers in Madagascar. These changes will not be felt uniformly across ecosystems or society, emphasising the need for nuanced and context-specific local management interventions. Coordinated action at regional and international scales will be critical, with attention urgently required on the distal drivers that are having profound impacts on reef ecosystems at the local level (Hughes et al., 2017).

In the face of intensifying climate drivers and multiscale anthropogenic threats, supporting transformative change in ocean governance requires transdisciplinary research approaches (Lombard et al., 2023). The research methodology employed in this thesis integrates transdisciplinary methods that bridge social and ecological

sciences, incorporating knowledge co-production techniques. These approaches yielded insights that would be unavailable through a single discipline investigation. Coproduction will have a critical role in the future of research in coral reef social-ecological systems, with potential to help close the gap between research and impact. Fostering research partnerships with local resource users is critical to decolonise conservation science and improve the evidence available for decision-makers, from local managers to global conservation leaders, to develop and deliver effective social and ecological management strategies. These strategies are urgently needed to sustain the livelihoods of reef-dependent communities amidst the backdrop of rapid social and ecological change in coral reef social-ecological systems.

Looking forward, I recognise four focused research priorities to help inform the sustainable management of reef-dependant small-scale fisheries:

1. Increase understanding of distal socioeconomic drivers that are causing local decline of reef fisheries.
2. Investigate empirical evidence linking co-management with social and ecological resilience in the face of global climate stressors.
3. Examine how co-management can promote social equity in the face of environmental and climate change.
4. Assess how knowledge co-production can minimise the “knowledge-action” gap and its potential to produce tangible ecological and social outcomes in small-scale fishing communities.

8.4 Reference List

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APPENDICES



Sunset in Tampolove. Image: ACarter

APPENDIX 1: Supporting Information for Chapter 4

Appendix 1.1: Abstract, Data Availability Statement and Acknowledgements for “Cyclone Impacts on Coral Reef Communities in Southwest Madagascar” Frontiers in Marine Science

Abstract: Tropical cyclones can cause severe destruction of coral reefs with ecological consequences for reef fish communities. Ocean warming is predicted to shorten the return interval for strong tropical cyclones. Understanding the consequences of cyclone impacts on coral reefs is critical to inform local-scale management to support reef resilience and the livelihood security of small-scale fishing communities. Here, we present the first analysis of a tropical cyclone disturbance on coral reefs in Madagascar. We investigate the impact of Cyclone Haruna (category 3 Saffir-Simpson scale) in February 2013 on coral communities, both adults and recruits, and explore the relationship between the severity of cyclone impact with cyclone parameters (wind speed, duration of storm impact and distance from cyclone track) and environmental variables (reef type and reef depth). We use survey data collected as part of a long-term citizen science monitoring programme at 21 coral reef sites between 2012 and 2015 in the Velondriake Locally Managed Marine Area along Madagascar’s southwest coast. Coral cover declined at 19 sites; however damage was spatially heterogeneous ranging from a decrease in coral cover of 1.4% to 45.8 %. We found the severity of cyclone damage related to: distance from the cyclone track, duration of cyclone impact and reef depth. The taxonomic and morphological composition of coral communities was significantly different after the cyclone. Notably, there was a decrease in the dominance of branching morphologies, and an increase in the relative abundance of encrusting and massive morphologies. Two years after Cyclone Haruna, mean coral cover had increased and the density of coral recruits increased to above pre-cyclone levels indicating the potential recovery of coral populations. However, recovery to pre-disturbance community composition will likely be hindered by the increasing occurrence of acute and chronic disturbance events.

Data Availability: The original contributions presented in the study are included in Appendix 1. Data is available here:

https://figshare.com/projects/southwest_Madagascar_coral_data/128954

Acknowledgements: We are grateful to the many field scientists and volunteers who aided in the collection of data for this study in addition to all the staff involved in the Blue Ventures Expeditions programme. Thank you to the boat captains who ensured our colleagues could safely conduct reef surveys and the Velondriake LMMA Management Association for allowing us to survey within the LMMA. Thank you to Prof. Sandy Tudhope for his helpful comments and review of the manuscript in its final stages and thank you to the anonymous reviewers who provided valuable comments to the earlier version of this manuscript.

Appendix 1.2

Table A1.2 The location of reef sites with reef type, reef depth and cyclone-associated parameters at each study site. Wind speed is the number of hours the cyclone was within 70km of the reef site, duration is the average maximum wind speed when the cyclone was within 70km of the reef site and min distance is the minimum distance from centre of the cyclone to the reef site in km. All sites included in generalised linear mixed model analysis.

Site	Latitude	Longitude	Reef type	Depth (m)	Duration (hours)	Wind speed (km/h)	Min. distance (km)
007	-22.123	43.197	Patch	11	24	159.5	27.4
Ampassy	-22.007	43.201	Patch	8	21	161.4	11.5
Ankafotia	-21.948	43.195	Barrier	11	18	163.3	38.4
Belamera	-22.012	43.199	Patch	9	21	161.4	10.2
Bic Cave	-22.174	43.220	Fringing	7	21	157.5	38.5
Christmas Reef	-22.054	43.190	Barrier	8	21	161.4	9.8
Fish Bowl	-22.077	43.185	Patch	10	21	161.4	13.8
Javic North	-22.115	43.219	Patch	7	24	159.5	24.6
Lost	-22.077	43.186	Barrier	4	21	161.4	13.9
Lovobe	-22.068	43.226	Patch	10	21	161.4	10.8
Mah	-22.092	43.225	Patch	5	24	159.5	17.1
Mobie	-21.993	43.244	Patch	3	18	163.3	37.2
NS Andavadoaka	-22.073	43.226	Fringing	6	21	161.4	11.9
NS Coco Beach	-22.084	43.227	Fringing	6	24	159.5	14.7
NS Halfmoon	-22.075	43.226	Fringing	5	24	159.5	14.7
Recruitment	-22.122	43.198	Patch	13	24	159.5	27.2
Shark Alley	-22.130	43.181	Barrier	10	24	159.5	30.0
South reef	-22.128	43.231	Fringing	5	21	161.38	9.6
Tampolove	-22.211	43.226	Patch	12	21	161.4	8.7
THB	-22.123	43.198	Patch	11	24	159.5	27.6
Vorea	-21.932	43.238	Barrier	6	18	163.3	39.3

Appendix 1.3

Table A1.3 Reef sites included in ANOSIM and SIMPER analysis for each category of benthic data. Surveys at each site were undertaken within one year before and after Cyclone Haruna (22nd February 2013).

Site	Latitude	Longitude	Adult coral community (> 10cm diameter)		Recruit and juvenile corals (<10cm diameter)
			Taxonomic composition	Morphological composition	Taxonomic Composition
007	-22.123	43.197	✓	✓	✓
Ampassy	-22.007	43.201	✓	✓	✓
Ankafotia	-21.948	43.195	✓		✓
Belamera	-22.012	43.199	✓	✓	✓
Bic Cave	-22.174	43.220	✓	✓	✓
Christmas Reef	-22.054	43.190	✓	✓	✓
Fish Bowl	-22.077	43.185		✓	
Javic North	-22.115	43.219		✓	
Lost	-22.077	43.186	✓	✓	✓
Lovobe	-22.068	43.226	✓	✓	✓
Mah	-22.092	43.225	✓	✓	✓
Mobie	-21.993	43.244	✓	✓	✓
NS Andavadoaka	-22.073	43.226	✓	✓	✓
NS Coco Beach	-22.084	43.227	✓	✓	✓
NS Halfmoon	-22.075	43.226	✓	✓	✓
Recruitment	-22.122	43.198	✓	✓	✓
Shark Alley	-22.130	43.181		✓	✓
Tampolove	-22.211	43.226		✓	
THB	-22.123	43.198	✓	✓	✓

Appendix 1.4

Table A1.4 Likelihood Ratio Test to test significance of fixed effects and interaction terms in the best performing model of hard coral cover. Full model in bold.

	Chi Squared	P value
<i>duration*BA + distance*BA + depth*BA</i>		
<i>duration*BA + distance*BA + depth</i>	22.8	1.776e-06 ***
<i>duration*BA + distance*BA</i>	23.0	1.01e-05 ***
<i>duration*BA + distance + depth*BA</i>	15.3	8.836e-05 ***
<i>duration*BA + depth*BA</i>	16.5	0.0002679 ***
<i>duration + distance*BA + depth*BA</i>	23.5	1.218e-06 ***
<i>distance*BA + depth*BA</i>	23.6	7.608e-06 ***
<i>BA</i>	82.0	1.378e-15 ***
<i>Null</i>	422.8	< 2.2e-16 ***

Appendix 1.5

Table A1.5 Intercept, standard error and P value for best performing model of hard coral cover. BA is before/after interaction term.

	Intercept	Standard Error	P value
Intercept	2.111	0.111	< 2e-16 ***
Duration	-0.103	0.109	0.343
BA:B	0.641	0.031	< 2e-16 ***
Distance	0.032	0.102	0.753
Depth	-0.136	0.116	0.242
Duration*BA:B	0.155	0.032	1.12e-06 ***
Distance*BA:B	0.123	0.111	8.42e-05 ***
Depth*BA:B	0.153	0.032	1.57e-06 ***

Appendix 1.6

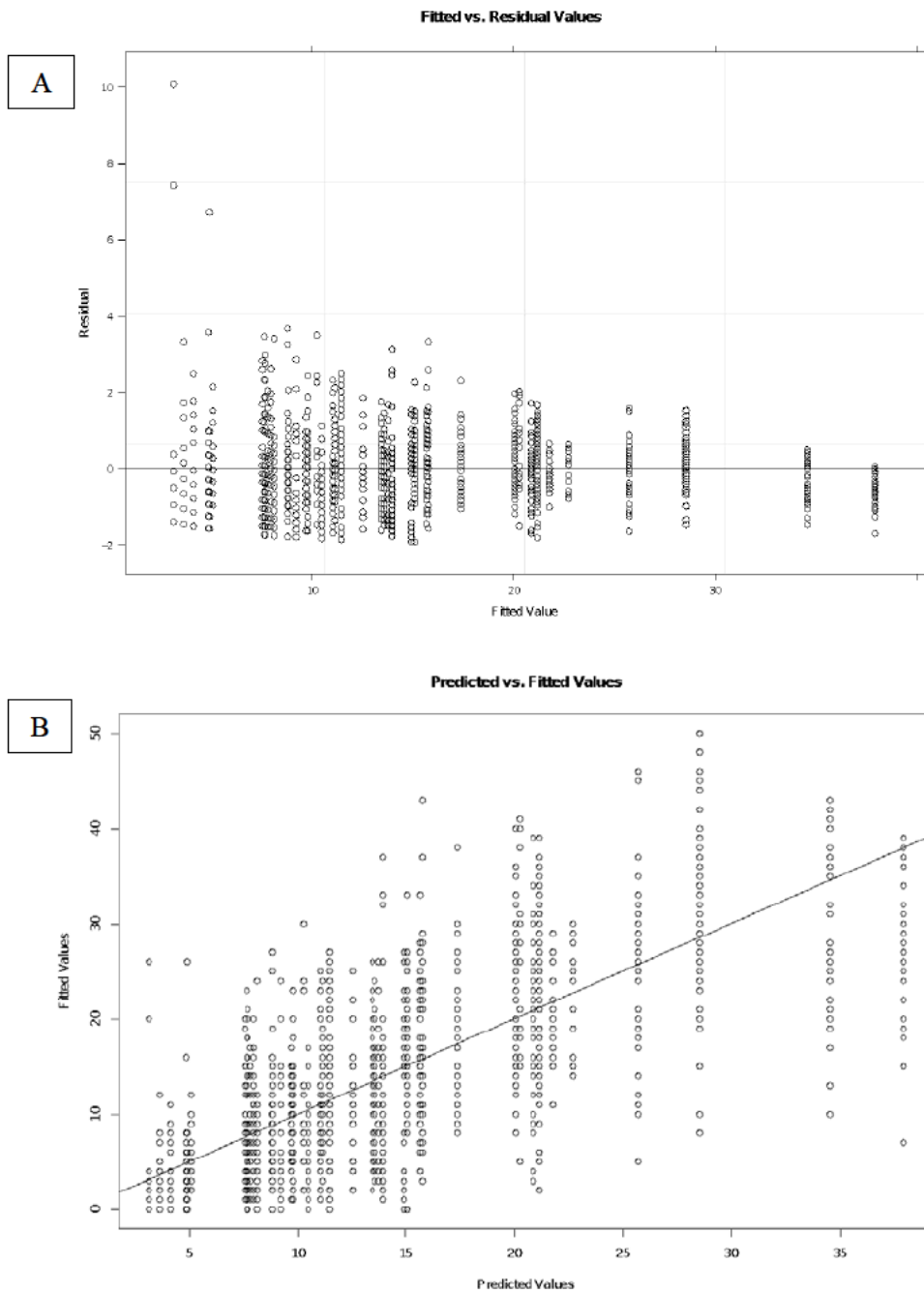


Figure A1.6 (A) Fitted vs. residual values plot and (B) predicted vs fitted values plot for best performing model for hard coral cover (HCC). HCC was modelled with a negative binomial distribution with a log link function.

Appendix 1.7

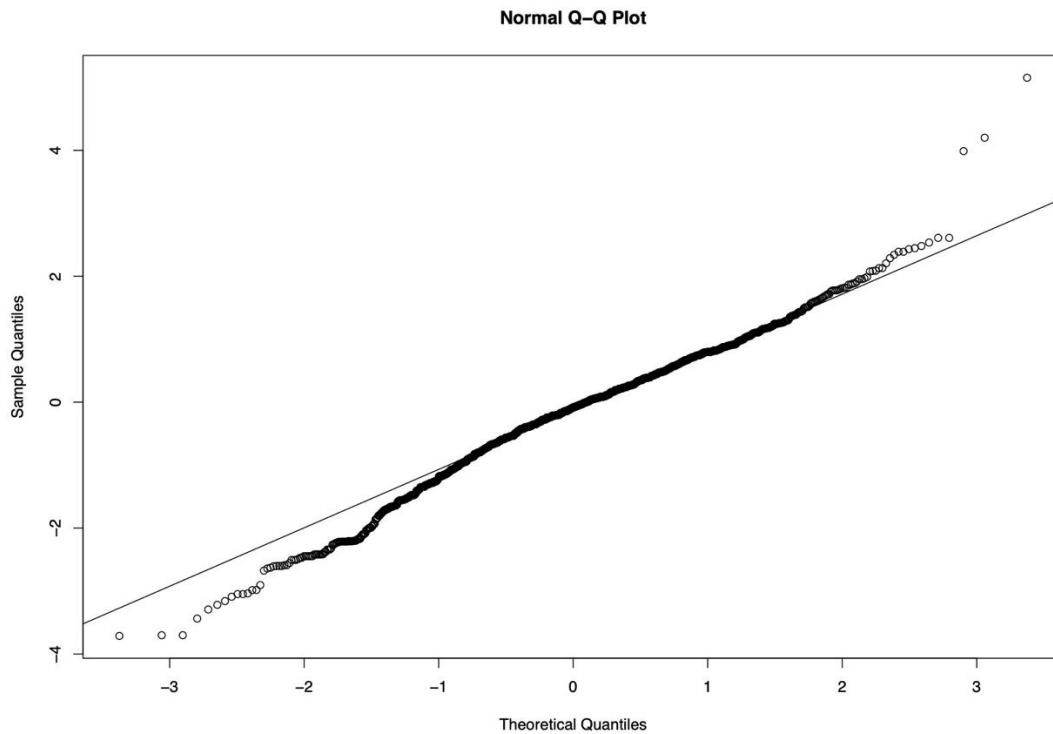


Figure A1.7 (A) Normal quantile-quantile plot of best performing model for hard coral cover (HCC). HCC was modelled with a negative binomial distribution with a log link function.

Appendix 1.8

Linear Model Analysis of Proportional Change in Hard Coral Cover

To corroborate the results of GLMM model analysis, we undertook further analysis using linear models to predict the proportional change in hard coral cover (HCC) before and after Cyclone Haruna ($\log(\text{HCC}_{\text{after}}/\text{HCC}_{\text{before}})$) as a function of cyclone parameters and reef characteristics. Average HCC values were calculated at each site for the two years before and two years after the cyclone.

The results of the linear model analysis were consistent with the GLMM analysis and the most parsimonious models based on AICc values ($\Delta\text{AIC} > 2$) contained cyclone parameters duration and distance and the reef characteristic depth (Table A1.8.1 and Table A1.8.2).

Table A1.8.1 AICc values for the most parsimonious linear models ($\Delta AIC > 2$) of proportional change in hard coral cover at each reef site before and after Cyclone Haruna ($\log(HCC_{after}/HCC_{before})$). The model contained cyclone parameters (i) wind (average maximum speed when the cyclone was within 70km of the reef site in m/s), (ii) duration (number of hours the cyclone was within 70km of the reef site) (iii) distance (min distance from centre of the cyclone to the reef site in km) and two reef characteristics (i) reef type and (ii) reef depth.

Fixed effects	K	AIC	ΔAIC	Log Likelihood	Adjusted R ²
<i>duration + distance + depth</i>	5	13.821	0.00	0.089	0.47
<i>duration + distance</i>	4	15.02	1.20	-2.258	0.37
<i>null</i>	2	21.059	7.24	-8.196	-

Table A1.8.2 Intercept, standard error and P value for best performing linear models of proportional change in hard coral cover before and after Cyclone Haruna.

Model		Intercept	Standard Error	P value
<i>duration + distance + depth</i>	Intercept	-0.654	0.060	4.81e-09 ***
	Depth	-0.131	0.063	0.055 .
	Distance	-0.126	0.055	0.036 *
	Duration	-0.182	0.059	0.007 **
<i>duration + distance</i>	Intercept	-0.642	0.065	1.18e-08***
	Distance	-0.137	0.060	0.034 *
	Duration	-0.210	0.063	0.004 **

APPENDIX 2: Supporting Information for Chapter 5

Appendix 2.1 Principal Component Analysis Principal component analysis is often used to calculate a Material Style of Life (MSL) index in social-ecological research (e.g. McClanahan et al., 2008; Gurney et al., 2014; D’agata et al., 2020; Pollnac and Crawford, 2000). PCA is used to assign weights or ‘loadings’ to the different material items within the MSL dataset. By assigning loadings, the index more accurately represents the significance of each variable in the index score. (Pollnac and Crawford, 2000) . The MSL scores are the sum of the component loadings times the sample standardized variables.

In this study MSL was estimated by the first axis of the principal coordinate analysis (Gurney et al., 2014). PCA was undertaken separately for 2016 and 2021. This was to reflect potential shifts in the significance of material items for wealth in that time period. The first principal components represented 29% and 32% of variance in the data set for 2016 and 2021, respectively (A2.1 Table 1 and 2). The small increase in variance from 29% to 32% indicates that the significance of material items for wealth may have shifted during this period. These scores are modest but within range of explained variance used for MSL analysis (Pollnac and Crawford, 2000).

Table A2.1.1 Factor loadings for the first principal component of 7 material items in 2016. This component accounted for 29% of the total variance.

Material Item	Factor Loading
Pirogue	-0.2482423
Motorised vehicle	-0.2570399
Television	-0.4477256
Radio	-0.4216765
Bed and Mattress	-0.3913743
Mobile	-0.4729532
Furniture (sofa/chairs/table)	-0.3811336

Table A2.1.2 Factor loadings for the first principal component of 7 material items in 2021. This component accounted for 32% of the total variance.

Material Item	Factor Loading
Pirogue	-0.1061344
Motorised vehicle	-0.1166086
Television	-0.4139114
Radio	-0.4216765
Bed and Mattress	-0.4671271
Mobile	-0.5099213
Furniture (sofa/chairs/table)	-0.3844174

APPENDIX 2.2 Tables containing values for adaptive capacity indicators for each grouping variable.

Description of each indicator and how it was measured is in Table 5.1 in main text; Material Style of Life (MSL).

Table A2.2.1 Values for adaptive capacity indicators for each village in 2016 and 2021

Year	Village	Habitat Type	MSL	Gear Diversity	Influence (%)	Participatio n	Educatio n (years)	Savings (%)	Livelihood diversity	Trust
2016	Agnolignoly	Mangrove	2.19 (±) 1.08	1.76 (±) 1.14	33.33	1.86 (±) 1.11	3.95 (±) 2.36	66.67	0.95 (±) 0.50	
2021	Agnolignoly	Mangrove	1.46 (±) 1.35	0.68 (±) 0.67	50.00	2.32 (±) 0.77	3.43 (±) 2.10	57.14	1.08 (±) 0.95	3.01 (±) 0.71
2016	Ambolimoke	Coastal	2.75 (±) 1.66	2.67 (±) 2.10	33.33	1.92 (±) 1.16	3.00 (±) 2.45	50.00	1.25 (±) 0.89	
2021	Ambolimoke	Coastal	1.59 (±) 1.27	1.21 (±) 1.59	44.83	2.14 (±) 0.83	2.86 (±) 3.92	44.83	0.60 (±) 0.70	3.34 (±) 0.88
2016	Andavadoaka	Coastal	2.34 (±) 1.29	1.14 (±) 1.39	36.36	1.27 (±) 1.23	6.14 (±) 3.20	36.36	0.42 (±) 0.67	
2021	Andavadoaka	Coastal	2.72 (±) 1.50	1.09 (±) 1.44	29.41	1.38 (±) 1.09	5.51 (±) 3.62	48.53	0.80 (±) 1.03	2.88 (±) 0.79
2016	Ankindranoke	Mangrove	1.14 (±) 1.01	1.19 (±) 1.03	23.81	1.76 (±) 1.26	1.86 (±) 2.01	33.33	1.03 (±) 0.98	
2021	Ankindranoke	Mangrove	1.09 (±) 1.20	0.41 (±) 0.56	28.13	1.75 (±) 1.14	2.38 (±) 2.76	34.38	0.36 (±) 0.65	3.09 (±) 0.87
2016	Ankitambagna	Coastal	2.07 (±) 1.39	2.47 (±) 2.17	53.33	2.20 (±) 0.94	3.20 (±) 3.10	46.67	0.59 (±) 0.69	
2021	Ankitambagna	Coastal	1.81 (±) 1.28	1.61 (±) 1.09	32.26	2.03 (±) 0.91	3.35 (±) 3.07	48.39	0.90 (±) 0.96	2.88 (±) 0.64

2016	Antsatsamoroy	Mangrove	2.12 (±) 1.05	1.53 (±) 0.72	52.94	2.47 (±) 0.87	3.47 (±) 2.15	35.29	1.09 (±) 1.09	
2021	Antsatsamoroy	Mangrove	1.97 (±) 1.44	1.41 (±) 1.32	29.73	2.19 (±) 1.00	4.08 (±) 3.54	45.95	0.36 (±) 0.62	2.82 (±) 0.66
2016	Antserananangy	Mangrove	2.10 (±) 1.79	2.00 (±) 2.54	50.00	2.10 (±) 0.99	3.80 (±) 2.15	30.00	0.86 (±) 0.85	
2021	Antserananangy	Mangrove	1.50 (±) 1.27	1.90 (±) 1.73	30.00	2.40 (±) 0.97	2.00 (±) 2.31	50.00	0.74 (±) 0.93	3.12 (±) 0.67
2016	Belavenoke	Mangrove	2.61 (±) 1.47	1.68 (±) 1.20	29.55	2.02 (±) 1.09	3.75 (±) 2.55	68.18	1.56 (±) 1.08	
2021	Belavenoke	Mangrove	2.62 (±) 1.44	1.31 (±) 1.23	24.59	1.85 (±) 1.11	3.07 (±) 2.48	59.02	0.21 (±) 0.51	2.92 (±) 0.89
2016	Bevato	Coastal	2.36 (±) 1.62	1.64 (±) 1.19	35.71	2.11 (±) 1.03	4.14 (±) 2.45	46.43	0.73 (±) 0.80	
2021	Bevato	Coastal	1.97 (±) 1.66	1.29 (±) 1.32	35.48	1.90 (±) 1.08	2.90 (±) 2.43	41.94	0.62 (±) 0.86	2.92 (±) 0.84
2016	Nosy Be	Island	2.29 (±) 1.40	2.04 (±) 1.43	50.00	2.21 (±) 0.88	2.54 (±) 3.18	37.50	0.94 (±) 1.03	
2021	Nosy Be	Island	1.98 (±) 1.27	1.76 (±) 1.52	33.33	2.24 (±) 0.83	1.82 (±) 2.28	60.00	0.50 (±) 0.71	3.12 (±) 0.76
2016	Nosy Mitata	Island	3.00 (±) 0.00	1.00 (±) 0.00	50.00	1.00 (±) 1.41	3.50 (±) 2.12	0.00	0.47 (±) 0.62	
2021	Nosy Mitata	Island	2.75 (±) 1.50	1.50 (±) 0.58	100.00	2.50 (±) 0.58	1.75 (±) 2.06	25.00	0.50 (±) 0.58	4.05 (±) 0.62

Table A2.2.2 Values for adaptive capacity indicators for men and women in 2021

Gender	MSL	Gear	Influence	Participation		Education	Savings	Livelihood	Trust
		Diversity	(%)		(years)	(%)	diversity		
Female	2.06 (±) 1.53	1.11 (±) 1.32	22.50	1.84 (±) 1.03	3.47 (±) 3.12	46.60	1.23 (±) 1.06	2.98 (±) 0.83	
Male	2.04 (±) 1.43	1.37 (±) 1.33	43.10	2.03 (±) 1.03	3.27 (±) 3.20	52.80	0.78 (±) 0.89	3.01 (±) 0.77	

A2.2.3 Values for adaptive capacity indicators between village habitat

Habitat Type	MSL	Gear Diversity	Influence (%)	Participatio n	Education (years)	Savings (%)	Livelihood diversity	Trust	Community Infrastructure
Coastal	2.20 (±)	1.26 (±)		1.74 (±)	4.07 (±)		0.97 (±)	2.97 (±)	
	1.52	1.39	33.50	1.05	3.56	46.80	1.03	0.80	8.84 (±) 3.70
Island	2.04 (±)	1.73 (±)		2.27 (±)	1.82 (±)		0.61 (±)	3.19 (±)	
	1.29	1.47	38.80	0.81	2.24	57.10	0.84	0.79	1.92 (±) 0.28
Mangrove	1.91 (±)	1.09 (±)		2.03 (±)	3.15 (±)		1.13 (±)	2.96 (±)	
	1.48	1.20	31.30	1.04	2.79	50.6	0.99	0.80	5.16 (±) 2.52

Table A2.2.4 Values for adaptive capacity indicators between age groups

Age Category	MSL	Gear Diversity	Influence (%)	Participation	Education (years)	Savings (%)	Livelihood diversity	Trust
Adult	2.30 (±) 1.52	1.38 (±) 1.42	39.40	2.16 (±) 0.87	3.38 (±) 3.31	57.80	1.14 (±) 1.03	3.04 (±) 0.80
Senior	1.65 (±) 1.54	1.08 (±) 1.31	44.60	2.11 (±) 1.03	3.05 (±) 3.31	31.10	0.92 (±) 0.95	2.96 (±) 0.77
Young Adult	1.93 (±) 1.32	1.17 (±) 1.18	18.30	1.54 (±) 1.12	3.60 (±) 2.90	48.6	0.86 (±) 0.97	2.93 (±) 0.79

APPENDIX 2.3

Results for Log-Likelihood Ratio Test and Akaike Information Criterion (AIC) for models investigating variation in adaptive capacity indicators. The below tables show the comparison between models containing the explanatory variable (full model) and a null model without the explanatory variable. $r(\text{Village})$ represents the random effect of village, included in all models unless the model did not converge in which case it was removed. The model structures were based on the type of data: linear mixed models for continuous data (MSL, Trust, Education), generalized linear mixed models (binomial family) with a logit link for binary response variables (Savings, Management Influence), generalized linear mixed models (poisson and negative binomial) for count (Gear Diversity, Community Infrastructure) and multinomial logistic mixed models with a cumulative logit link for the ordinal response variables (Livelihood Diversity, Management Participation).

Abbreviations in the following tables: Akaike Information Criterion (AIC), number degrees of freedom (#Df), Log Likelihood (LogLik), difference in degrees of freedom (Dif_df), Chi-squared statistic (Chisq) and p-value associated with Likelihood Ratio Test between full and null model $\text{Pr}(>\text{Chisq})$, Material Style of Life (MSL).

Significance levels: *** = significant at 0.001, ** = significant at $p=0.01$, * = significant at $p=0.05$.

Table A2.3.1 Log-Likelihood Ratio Test and Akaike Information Criterion (AIC) for variation in adaptive capacity between different village habitats (Habitat), age group (Age) and gender.

Response Variable	Model (Y is response variable)	AIC	#Df	LogLik	Df	Chisq	Pr(>Chisq)
Savings	Y ~ 1	509.34	1	-253.67			
	Y ~ Habitat	511.982	3	-252.99	2	1.3581	0.5071
Gear Diversity	Y ~ 1 + r(Village)	1101.2	3	-547.59			
	Y ~ Habitat + r(Village)	1102.4	5	-546.23	2	2.7237	0.2562
MSL	Y ~ 1 + r(Village)	1261.489	3	-465.74			
	Y ~ Habitat + r(Village)	1264.133	5	-466.08	2	1.3555	0.6735
Livelihood	Y ~ 1 + r(Village)	827.1901	4	-409.6			
Diversity	Y ~ Habitat + r(Village)	820.2565	6	-404.13	2	10.934	0.004225**
Trust	Y ~ 1 + r(Village)	875.1526	3	-434.58			
	Y ~ Habitat + r(Village)	881.1621	5	-435.58	2	2.0095	0.3661
Management	Y ~ 1	471.977	1	-234.99			
Influence	Y ~ Habitat	474.8636	3	-234.43	2	1.1134	0.5731
Management	Y ~ 1 + r(Village)	933.5051	4	-462.75			
Participation	Y ~ Habitat + r(Village)	934.1059	6	-461.05	2	3.3992	0.1828
Education	Y ~ 1 + r(Village)	1862.537	3	-928.27			
	Y ~ Year + r(Village)	1860.15	5	-925.08	2	6.3867	0.04103*
		1339.972	2	-667.99			

Community	Y ~ 1						
Infrastructure	Y ~ Year	1335.347	4	-663.67	2	8.6255	0.0134 *
Savings	Y ~ 1	509.3400	3	-253.67			
	Y ~ Age	507.2108	4	-251.60	1	4.1292	0.04215 *
Gear Diversity	Y ~ 1 + r(Village)	1101.178	3	-547.59			
	Y ~ Age + r(Village)	1100.698	4	-547.51	1	0.1668	0.683
MSL	Y ~ 1 + r(Village)	1261.489	3	-628.74			
	Y ~ Age + r(Village)	1264.133	4	-628.07	1	1.3555	0.5078
Livelihood	Y ~ 1 + r(Village)	827.1901	4	-409.60			
Diversity	Y ~ Age + r(Village)	825.5507	6	-407.78	1	3.6394	0.05643
Trust	Y ~ 1 + r(Village)	875.1526	3	-434.58			
	Y ~ Age + r(Village)	880.9308	5	-436.47	1	3.7782	0.05192
Management	Y ~ 1	471.977	1	-234.99			
Influence	Y ~ Age	458.2147	2	-227.11	1	15.762	7.182e-05 ***
Management	Y ~ 1 + r(Village)	933.5051	4	-462.75			
Participation	Y ~ Age + r(Village)	918.8358	5	-454.42	1	16.669	4.449e-05 ***
Education	Y ~ 1 + r(Village)	1862.537	3	-928.27			
	Y ~ Age + r(Village)	1865.406	5	-928.70	1	0.8686	0.3513
Savings	Y ~ 1	509.34	1	-253.67			
	Gender	509.9861	2	-252.99	1	1.3539	0.2446
Gear Diversity	Y ~ 1 + r(Village)	1101.146	3	-547.57			
	Gender + r(Village)	1100.183	4	-546.09	1	2.9631	0.08518
MSL	Y ~ 1 + r(Village)	1261.489	2	-628.74			

	Gender + r(Village)	1263.486	3	-628.74	1	0.0033	0.9539
Livelihood	Y ~ 1 + r(Village)	827.1901	4	-409.6			
Diversity	Gender + r(Village)	807.3813	5	-398.69	1	21.809	3.01E-06***
Trust	Y ~ 1 + r(Village)	875.1526	3	-434.58			
	Gender + r(Village)	880.1525	4	-436.08	1	2.9999	0.08327
Management	Y ~ 1	471.977	2	-225.95			
Influence	Gender	455.903	1	-234.99	-1	18.074	2.13E-05***
Management	Y ~ 1 + r(Village)	933.5051	4	-462.75			
Participation	Gender + r(Village)	931.404	5	-460.7	1	4.1011	0.04285*
Education	Y ~ 1 + r(Village)	1862.537	3	-928.27			
	Gender + r(Village)	1864.779	4	-928.39	1	0.2422	0.6226

Table A2.3.2 Log-Likelihood Ratio Test and Akaike Information Criterion (AIC) for investigating change in adaptive capacity between 2016 and 2021 for adaptive capacity indicators for men and women. Response variable in bold.

Response Variable	Model (Y is response variable)	AIC	#Df	LogLik	Df	Chisq	Pr(>Chisq)
Female							
Gear Diversity	Y ~ 1 + r(Village)	850.1251	3	-422.06			
	Y ~ Year + r(Village)	852.0079	4	-422	1	0.1172	0.7321
Management Influence	Y ~ 1	336.0487	1	-167.02			
	Y ~ Year	337.4052	2	-166.7	1	0.6435	0.4224
Management Participation	Y ~ 1 + r(Village)	777.1168	4	-384.56			
	Y ~ Year + r(Village)	778.8726	5	-384.44	1	0.2443	0.6211
Education	Y ~ 1 + r(Village)	1479.629	4	-735.05			
	Y ~ Year + r(Village)	1478.097	3	-736.81	-1	3.532	0.06019
Savings	Y ~ 1	412.3793	3	-204.12			
	Y ~ Year	414.2374	2	-204.19	-1	0.1419	0.7064
MSL	Y ~ 1 + r(Village)	1043.798	3	-519.89			
	Y ~ Year + r(Village)	1045.782	2	-519.9	-1	0.016	0.899
Livelihood Diversity	Y ~ 1 + r(Village)	777.3024	3	-370.69			
	Y ~ Year + r(Village)	747.3895	2	-386.65	-1	31.913	1.61E-08***

Male							
Gear Diversity	Y ~ 1 + r(Village)	1039.458	3	-516.73			
	Y ~ Year + r(Village)	1014.677	4	-503.34	1	26.781	2.28E-07***
Management Influence	Y ~ 1	424.3218	1	-211.16			
	Y ~ Year	425.4498	2	-210.72	1	0.872	0.3504
Management Participation	Y ~ 1 + r(Village)	764.7184	4	-378.36			
	Y ~ Year + r(Village)	1547.981	5	-378.27	1	0.1803	0.6711
Education	Y ~ 1 + r(Village)	1549.868	3	-770.99			
	Y ~ Year + r(Village)	1553.086	4	-770.93	1	3.105	0.07805
Savings	Y ~ 1	427.271	3	-211.48			
	Y ~ Year	428.9603	2	-211.64	1	0.3108	0.5772
MSL	Y ~ 1 + r(Village)	1047.407	2	-521.7			
	Y ~ Year + r(Village)	1045.513	3	-519.76	1	3.8932	0.05848
Livelihood Diversity	Y ~ 1 + r(Village)	656.3827	4	-324.19			
	Y ~ Year + r(Village)	645.0118	5	-317.51	1	13.371	0.0002556***

Table A2.3.3 Log-Likelihood Ratio Test and Akaike Information Criterion (AIC) for models containing perceived climate impacts (climate), recovery of food access following COVID-19 (food) and recovery of income following COVID-19 (income).

Response Variable	Model (Y is response variable)	AIC	#Df	LogLik	Dif_Df	Chisq	Pr(>Chisq)
Savings	Y ~ 1 + r(Village)	505.2001	1	-249.70			
	Y ~ Climate + r(Village)	507.3967	4	-251.6	-3	3.8034	0.2835
Gear Diversity	Y ~ 1 + r(Village)	1094.389	3	-544.19			
	Y ~ Climate + r(Village)	1098.622	6	-543.31	-3	1.7677	0.622
MSL	Y ~ 1 + r(Village)	926.58	3	-460.29			
	Y ~ Climate + r(Village)	924.18	6	-456.09	-3	8.3987	0.03845*
Livelihood Diversity	Y ~ 1 + r(Village)	821.6693	4	-406.68			
	Y ~ Climate + r(Village)	827.3594	7	-406.83	-3	0.3098	0.9582
Trust	Y ~ 1 + r(Village)	869.6889	3	-431.84			
	Y ~ Climate + r(Village)	875.0273	6	-431.51	3	0.6616	0.8822
Management Influence	Y ~ 1	468.1571	1	-233.08			
	Y ~ Climate	451.9331	4	-221.97	3	22.224	5.86E-05***
Management Participation	Y ~ 1 + r(Village)	925.3664	4	-458.68			
	Y ~ Climate + r(Village)	897.9407	7	-441.97	3	33.426	2.62E-07***
Education	Y ~ 1 + r(Village)	1845.8	3	-919.91			
	Y ~ Climate + r(Village)	1848	6	-918	3	3.8283	0.2806

Community	Y ~ 1 + r(Village)	1331.851	2	-662.93			
Infrastructure	Y ~ Climate + r(Village)	1337.849	5	-662.92	3	0.0019	1
Gear Diversity	Y ~ 1 + r(Village)	1091.397	3	-542.70			
	Y ~ Income + r(Village)	1086.900z	5	-538.45	2	8.4974	0.01428 *
Management	Y ~ 1	467.7628	1	-232.88			
Influence	Y ~ Income	469.7256	3	-231.86	2	2.0373	0.3611
Management	Y ~ 1 + r(Village)	916.06	4	-454.03			
Participation	Y ~ Income + r(Village)	919.16	6	-453.58	2	0.9033	0.6366
Education	Y ~ 1 + r(Village)	1842.241	3	-917.06			
	Y ~ Income + r(Village)	1840.111	5	-916.12	-2	1.8703	0.3925
Savings	Y ~ 1	502.4495	1	-250.22			
	Y ~ Income	493.5405	3	-243.77	-2	12.909	0.001573**
MSL	Y ~ 1	925.9308	3	-459.97			
	Y ~ Income	927.2420	5	-458.62	-2	2.6888	0.2607
Livelihood	Y ~ 1 + r(Village)	818.5634	3	-412.81			
Diversity	Y ~ Income + r(Village)	831.0491	5	-410.52	2	4.5617	0.1022
Trust	Y ~ 1 + r(Village)	864.5784	3	-429.29			
	Y ~ Income + r(Village)	867.2334	5	-428.62	2	1.345	0.5104
Community	Y ~ 1 + r(Village)	1319.508	2	-657.75			
infrastructure	Y ~ Income + r(Village)	1323.505	4	-657.75	2	0.0033	0.9983
Gear Diversity	Y ~ 1 + r(Village)	1088.936	3	-541.47			

	Y ~ Food + r(Village)	1087.293	5	-538.65	2	5.6421	0.05954
Management	Y ~ 1 + r(Village)	465.6365	1	-231.82			
Influence	Y ~ Food + r(Village)	466.4143	3	-230.21	2	3.222	0.1997
Management	Y ~ 1 + r(Village)	1023.199	4	-508.60			
Participation	Y ~ Food + r(Village)	1016.709	6	-503.35	2	10.49	0.005275 **
Education	Y ~ 1 + r(Village)	1836.262	5	-912.89			
	Y ~ Food + r(Village)	1831.785	3	-913.13	2	0.4765	0.788
Savings	Y ~ 1	501.0660	1	-238.42			
	Y ~ Food	482.8388	3	-249.53	2	22.225	1.49E-05***
MSL	Y ~ 1 + r(Village)	921.6679	2	-622.79			
	Y ~ Food + r(Village)	922.1094	4	-619.03	2	7.5104	0.1688
Livelihood	Y ~ 1 + r(Village)	816.7269	3	-404.36			
Diversity	Y ~ Food + r(Village)	816.6834	5	-402.34	2	4.035	0.1324
Trust	Y ~ 1 + r(Village)	866.9107	3	-512.28			
	Y ~ Food + r(Village)	868.3047	5	-511.09	2	2.3954	0.3019
Community	Y ~ 1 + r(Village)	1317.774	2	-656.89			
infrastructure	Y ~ Food + r(Village)	1321.768	4	-656.88	2	0.0062	0.9969

APPENDIX 2. 3 Additional analyses for investigating adaptive capacity

In this analysis, the response variable (age, habitat, gender, year, recovery of income, recovery of food and perceived climate impact) served as the grouping variable. The adaptive capacity indicators were employed as explanatory variables within a single model. Model structures were determined by the structure of the response variable, these were: generalised linear models with identity link (age), generalised linear model with a logit link for binary response (year, gender), multinomial generalised linear model for unordered category (habitat) and proportional odds logistic regression for ordered category (recovery of income, recovery of food and perceived climate impact). Summary outputs for each model, along with an assessment of the fixed effects based on the Akaike Information Criterion (AIC), are presented in the following pages.

For each grouping variable, the first table displays the model summary, including p-values associated with each fixed factor in the model (*Column Pr(>|z|)*) or t-values (*t value*). A p-value is considered significant at $p < 0.05$ and t-values are considered significant if $t \text{ value} > 2$. The second table presents AIC values and Likelihood Ratio Tests for nested models.

Interpreting AIC Values in the table

The row labelled *<none>* in the table corresponds to the AIC of the full model. The *Delta_AIC* column represents the difference between the AIC of the full model and the AIC when the explanatory variable of that row is omitted. A negative change in AIC (in the *Delta_AIC* column) of -5 is indicative of the explanatory variable significantly improving the model.

Interpreting Likelihood Ratio Test Values in the Table

Likelihood Ratio Tests assess the fit of nested models. A p-value (*Pr(>Chi)*) below 0.05 suggests that the model which includes the specified explanatory variable, significantly improves the model.

Model output and AIC values for variation between adaptive capacity indicators and different social groups:

Gender

```
Call:
glm(formula = gender ~ scale(average_trust) + scale(NRM_attend_code) +
     scale(NRM_influence_code) + scale(savings) + scale(sum_gear_columns) +
     scale(assets) + scale(livsscore) + scale(education) + scale(infrastructure),
     family = binomial("logit"), data = clim21)
```

```
Deviance Residuals:
    Min       1Q   Median       3Q      Max
-2.1402 -1.0580 -0.6112  1.0842  1.8073
```

```
Coefficients:
                Estimate Std. Error z value Pr(>|z|)
(Intercept)      -0.11668    0.11266  -1.036   0.3003
scale(average_trust)  0.04839    0.11561   0.419   0.6755
scale(NRM_attend_code) -0.06326    0.12754  -0.496   0.6199
scale(NRM_influence_code) -0.50416    0.12767  -3.949 7.85e-05 ***
scale(savings)     -0.10615    0.12213  -0.869   0.3848
scale(sum_gear_columns) -0.22349    0.13232  -1.689   0.0912 .
scale(assets)       0.03048    0.13762   0.221   0.8247
scale(livsscore)    0.60152    0.12546   4.795 1.63e-06 ***
scale(education)    0.02623    0.12616   0.208   0.8353
scale(infrastructure) -0.10005    0.12640  -0.792   0.4286
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

(Dispersion parameter for binomial family taken to be 1)

```
Null deviance: 502.23 on 362 degrees of freedom
Residual deviance: 454.47 on 353 degrees of freedom
AIC: 474.47
```

Number of Fisher Scoring iterations: 4

	Df	Deviance	AIC	LRT	Pr(>Chi)	Delta_AIC
<none>	NA	454.4661	474.4661	NA	NA	0.0000000
scale(livsscore)	1	480.1225	498.1225	25.65645367	4.079290e-07	-23.6564537
scale(NRM_influence_code)	1	470.8125	488.8125	16.34648647	5.275387e-05	-14.3464865
scale(sum_gear_columns)	1	457.3739	475.3739	2.90782688	8.815058e-02	-0.9078269
scale(infrastructure)	1	455.0944	473.0944	0.62834535	4.279629e-01	1.3716546
scale(NRM_attend_code)	1	454.7122	472.7122	0.24617046	6.197846e-01	1.7538295
scale(average_trust)	1	454.6414	472.6414	0.17536233	6.753895e-01	1.8246377
scale(assets)	1	454.5151	472.5151	0.04904448	8.247344e-01	1.9509555
scale(education)	1	454.5093	472.5093	0.04324442	8.352657e-01	1.9567556

Age

```
Call:
glm(formula = scale(age_cat_recode) ~ scale(NRM_attend_code) +
  scale(NRM_influence_code) + scale(savings) + scale(sum_gear_columns) +
  scale(assets) + scale(livsscore) + scale(education), data = clim21)
```

```
Deviance Residuals:
    Min       1Q   Median       3Q      Max
-1.88874  -0.81632   0.04772   0.48495   1.98667
```

```
Coefficients:
              Estimate Std. Error t value Pr(>|t|)
(Intercept)   -5.300e-16  5.041e-02   0.000  1.00000
scale(NRM_attend_code)  1.585e-01  5.563e-02   2.849  0.00464 **
scale(NRM_influence_code)  1.666e-01  5.569e-02   2.991  0.00297 **
scale(savings)  -1.379e-01  5.457e-02  -2.527  0.01194 *
scale(sum_gear_columns)  -3.425e-03  5.774e-02  -0.059  0.95273
scale(assets)    -1.142e-02  6.114e-02  -0.187  0.85192
scale(livsscore)  9.160e-02  5.200e-02   1.762  0.07900 .
scale(education) -8.019e-02  5.403e-02  -1.484  0.13863
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
(Dispersion parameter for gaussian family taken to be 0.9225625)
```

```
Null deviance: 362.00 on 362 degrees of freedom
Residual deviance: 327.51 on 355 degrees of freedom
AIC: 1010.8
```

```
Number of Fisher Scoring iterations: 2
```

	Df	Deviance	AIC	scaled dev.	Pr(>Chi)	Delta_AIC
<none>	NA	327.5097	1010.802	NA	NA	0.0000000
scale(NRM_influence_code)	1	335.7642	1017.838	9.035619026	0.002647694	-7.0356190
scale(NRM_attend_code)	1	334.9972	1017.008	8.205490652	0.004176381	-6.2054907
scale(savings)	1	333.4012	1015.274	6.471901548	0.010959321	-4.4719015
scale(livsscore)	1	330.3726	1011.961	3.159312719	0.075494960	-1.1593127
scale(education)	1	329.5420	1011.048	2.245631552	0.133992192	-0.2456316
scale(assets)	1	327.5419	1008.838	0.035682677	0.850172300	1.9643173
scale(sum_gear_columns)	1	327.5129	1008.806	0.003597703	0.952170885	1.9964023

Habitat

```
habitat_model <- vglm(as.factor(habitat_type) ~ scale(average_trust) +
  scale(NRM_attend_code) + scale(NRM_influence_code) +
  scale(savings) + scale(sum_gear_columns) + scale(livsscore) +
  scale(education) + scale(infrastructure) + scale(assets),
  family = multinomial, data = clim21)
```

	Estimate	Std. Error	z value	Pr(> z)
(Intercept):Island	-42.19723	82.08412	-0.513	0.6085
(Intercept):Mangrove	0.22284	0.13411	1.661	0.0968
scale(average_trust):Island	0.01062	0.30735	0.0346	0.9729
scale(average_trust):Mangrove	-0.06773	0.1328	-0.5104	0.6098
scale(NRM_attend_code):Island	0.06898	0.37145	0.1861	0.8524
scale(NRM_attend_code):Mangrove	0.08373	0.15392	0.5434	0.5865
scale(NRM_influence_code):Island	-0.35557	0.30252	-1.175	0.2396
scale(NRM_influence_code):Mangrove	-0.24143	0.15138	-1.593	0.1114
scale(savings):Island	-0.14894	0.32527	-0.4576	0.6473
scale(savings):Mangrove	0.1178	0.1464	0.805	0.4203
scale(sum_gear_columns):Island	0.24126	0.36422	0.661	0.5085
scale(sum_gear_columns):Mangrove	-0.38259	0.16287	-2.348	0.0189 *
scale(livsscore):Island	-0.52697	0.36111	-1.459	0.1444
scale(livsscore):Mangrove	0.24313	0.14129	1.721	0.0852
scale(education):Island	-0.76007	0.39535	-1.924	0.0543 *
scale(education):Mangrove	-0.201	0.15114	-1.331	0.1836
scale(infrastructure):Island	-39.53912	73.60352	-0.538	0.5906
scale(infrastructure):Mangrove	-1.44515	0.19082	-7.566	4.01E-14 ***
scale(assets):Island	0.68683	0.38814	1.77	0.0767 *
scale(assets):Mangrove	0.23505	0.16469	1.428	0.1533

	Df	Deviance	AIC	LRT	Pr(>Chi)	Delta_AIC
<none>	NA	429.5593	469.5593	NA	NA	0.0000000
scale(infrastructure)	2	660.1034	696.1034	230.5440957	8.669334e-51	-226.54409565
scale(sum_gear_columns)	2	438.1788	474.1788	8.6194634	1.343715e-02	-4.61946341
scale(livsscore)	2	438.1277	474.1277	8.5683524	1.378497e-02	-4.56835237
scale(education)	2	433.8834	469.8834	4.3241053	1.150886e-01	-0.32410530
scale(assets)	2	433.5117	469.5117	3.9523642	1.385974e-01	0.04763577
scale(NRM_influence_code)	2	432.4395	468.4395	2.8801513	2.369098e-01	1.11984867
scale(savings)	2	430.9032	466.9032	1.3438549	5.107232e-01	2.65614507
scale(average_trust)	2	429.8777	465.8777	0.3183258	8.528574e-01	3.68167421
scale(NRM_attend_code)	2	429.8560	465.8560	0.2966928	8.621324e-01	3.70330716

Model output and AIC values for assessing change in adaptive capacity indicators between 2016 and 2021:

Male

Call:

```
glm(formula = factor(Year) ~ scale(NRM_attend_code) + scale(NRM_influence_code) +
  scale(savings) + scale(sum_gear_columns) + scale(assets) +
  scale(livsscore) + scale(education), family = binomial(link = "logit"),
  data = man)
```

Deviance Residuals:

Min	1Q	Median	3Q	Max
-2.25987	-0.00025	0.52020	0.69370	2.01575

Coefficients:

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	-1.994543	119.924894	-0.017	0.9867
scale(NRM_attend_code)	-0.002144	0.166670	-0.013	0.9897
scale(NRM_influence_code)	-0.055969	0.166827	-0.335	0.7373
scale(savings)	0.316210	0.164925	1.917	0.0552
scale(sum_gear_columns)	-0.930096	0.180204	-5.161	2.45e-07 ***
scale(assets)	0.035468	0.176764	0.201	0.8410
scale(livsscore)	-8.365347	319.585789	-0.026	0.9791
scale(education)	-0.111652	0.166528	-0.670	0.5026

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for binomial family taken to be 1)

Null deviance: 403.05 on 305 degrees of freedom

Residual deviance: 267.64 on 298 degrees of freedom

AIC: 283.64

Number of Fisher Scoring iterations: 17

	Df	Deviance	AIC	LRT	Pr(>Chi)	Delta_AIC
<none>	NA	454.4661	474.4661	NA	NA	0.0000000
scale(livsscore)	1	480.1225	498.1225	25.65645367	4.079290e-07	-23.6564537
scale(NRM_influence_code)	1	470.8125	488.8125	16.34648647	5.275387e-05	-14.3464865
scale(sum_gear_columns)	1	457.3739	475.3739	2.90782688	8.815058e-02	-0.9078269
scale(infrastructure)	1	455.0944	473.0944	0.62834535	4.279629e-01	1.3716546
scale(NRM_attend_code)	1	454.7122	472.7122	0.24617046	6.197846e-01	1.7538295
scale(average_trust)	1	454.6414	472.6414	0.17536233	6.753895e-01	1.8246377
scale(assets)	1	454.5151	472.5151	0.04904448	8.247344e-01	1.9509555
scale(education)	1	454.5093	472.5093	0.04324442	8.352657e-01	1.9567556

Female

Call:

```
glm(formula = factor(Year) ~ scale(NRM_attend_code) + scale(NRM_influence_code) +
  scale(savings) + scale(sum_gear_columns) + scale(assets) +
  scale(livsscore) + scale(education), family = binomial(link = "logit"),
  data = fem)
```

Deviance Residuals:

Min	1Q	Median	3Q	Max
-1.75314	-0.00014	0.74772	0.80852	0.98798

Coefficients:

	Estimate	Std. Error	z value	Pr(> z)
(Intercept)	-4.01129	253.12492	-0.016	0.987
scale(NRM_attend_code)	0.07156	0.16216	0.441	0.659
scale(NRM_influence_code)	0.07251	0.16694	0.434	0.664
scale(savings)	0.03248	0.15127	0.215	0.830
scale(sum_gear_columns)	-0.06990	0.15465	-0.452	0.651
scale(assets)	0.06182	0.16830	0.367	0.713
scale(livsscore)	-10.89482	554.25002	-0.020	0.984
scale(education)	-0.10790	0.15550	-0.694	0.488

(Dispersion parameter for binomial family taken to be 1)

Null deviance: 405.35 on 297 degrees of freedom
 Residual deviance: 280.44 on 290 degrees of freedom
 AIC: 296.44

Number of Fisher Scoring iterations: 18

	Df	AIC	LRT	Pr(>Chi)	Delta_AIC
<none>	NA	684.1757	NA	NA	0.000000
scale(education)	1	682.7616	0.5859259	0.44399887	1.414074
scale(average_trust)	1	687.1033	4.9276725	0.02642989	-2.927673
scale(livsscore)	1	686.6307	4.4550565	0.03479807	-2.455056
scale(NRM_attend_code)	1	685.8866	3.7109327	0.05405718	-1.710933
scale(assets)	1	685.5086	3.3329553	0.06790476	-1.332955
scale(infrastructure)	1	682.7287	0.5530648	0.45706813	1.446935
scale(savings)	1	682.5185	0.3428234	0.55820403	1.657177
scale(sum_gear_columns)	1	682.4094	0.2337063	0.62878917	1.766294
scale(NRM_influence_code)	1	682.3953	0.2196855	0.63927963	1.780314

Model output for assessing the relationship between adaptive capacity indicators and recovery of food access and income following COVID-19:

Recovery of Income

Call:
 polr(formula = as.factor(covid_income_return) ~ scale(average_trust) +
 scale(NRM_attend_code) + scale(NRM_influence_code) + scale(sum_gear_columns) +
 scale(savings) + scale(assets) + scale(livsscore) + scale(education) +
 scale(infrastructure), data = clim21)

Coefficients:

	Value	Std. Error	t value
scale(average_trust)	0.10694	0.1182	0.9051
scale(NRM_attend_code)	0.03196	0.1327	0.2409
scale(NRM_influence_code)	-0.15487	0.1286	-1.2039
scale(sum_gear_columns)	0.24271	0.1293	1.8772
scale(savings)	-0.05997	0.1257	-0.4770
scale(assets)	0.14516	0.1395	1.0404
scale(livsscore)	0.17105	0.1131	1.5119
scale(education)	-0.11160	0.1282	-0.8702
scale(infrastructure)	0.25748	0.1249	2.0616

Intercepts:

	Value	Std. Error	t value
less more	0.8534	0.1190	7.1735
more same	1.7725	0.1506	11.7662

Residual Deviance: 580.3839
 AIC: 602.3839

	Df	AIC	LRT	Pr(>Chi)	Delta_AIC
<none>	NA	602.3839	NA	NA	0.0000000
scale(NRM_influence_code)	1	601.8531	1.46923821	0.22546593	0.5307618
scale(assets)	1	601.4646	1.08072135	0.29853624	0.9192787
scale(infrastructure)	1	604.6379	4.25405331	0.03915677	-2.2540533
scale(sum_gear_columns)	1	603.8915	3.50767942	0.06108496	-1.5076794
scale(livsscore)	1	602.6398	2.25594365	0.13310230	-0.2559437
scale(average_trust)	1	601.2076	0.82378142	0.36407688	1.1762186
scale(education)	1	601.1517	0.76781500	0.38089385	1.2321850
scale(savings)	1	600.6117	0.22782037	0.63314472	1.7721796
scale(NRM_attend_code)	1	600.4420	0.05816849	0.80941450	1.9418315

Recovery of Food Access

Call:
 polr(formula = as.factor(covid_food_return) ~ scale(average_trust) +
 scale(NRM_attend_code) + scale(NRM_influence_code) + scale(savings) +
 scale(sum_gear_columns) + scale(assets) + scale(livsscore) +
 scale(education) + scale(infrastructure), data = clim21)

Coefficients:

	Value	Std. Error	t value
scale(average_trust)	0.151883	0.1094	1.3887
scale(NRM_attend_code)	-0.380204	0.1236	-3.0769
scale(NRM_influence_code)	-0.022480	0.1187	-0.1894
scale(savings)	-0.297426	0.1166	-2.5501
scale(sum_gear_columns)	0.003258	0.1193	0.0273
scale(assets)	0.257955	0.1305	1.9767
scale(livsscore)	0.152733	0.1071	1.4265
scale(education)	-0.049761	0.1184	-0.4202
scale(infrastructure)	0.015437	0.1174	0.1315

Intercepts:

	Value	Std. Error	t value
less more	0.4002	0.1111	3.6010
more same	1.6792	0.1460	11.5044

Residual Deviance: 659.2176
 AIC: 681.2176

	Df	AIC	LRT	Pr(>Chi)	Delta_AIC
<none>	NA	681.2176	NA	NA	0.0000000
scale(average_trust)	1	681.1618	1.9441700212	0.16321647	0.05582998
scale(NRM_attend_code)	1	688.7629	9.5452178822	0.00200471	-7.54521788
scale(savings)	1	685.8187	6.6010618010	0.01019180	-4.60106180
scale(assets)	1	683.1520	3.9343930053	0.04730821	-1.93439301
scale(livsscore)	1	681.2423	2.0246675511	0.15476279	-0.02466755
scale(education)	1	679.3950	0.1773868237	0.67362865	1.82261318
scale(NRM_influence_code)	1	679.2535	0.0359036318	0.84971464	1.96409637
scale(infrastructure)	1	679.2349	0.0172787772	0.89542032	1.98272122
scale(sum_gear_columns)	1	679.2184	0.0007451541	0.97822244	1.99925485

Model output for assessing relationship between adaptive capacity indicators and perceived impact of chronic climate stressors:

Call:

```
MASS::polr(formula = climate ~ scale(average_trust) + scale(NRM_attend_code) +
  scale(NRM_influence_code) + scale(savings) + scale(sum_gear_columns) +
  scale(pca) + scale(livsscore) + scale(education) + scale(total),
  data = clim21, Hess = TRUE)
```

Coefficients:

	Value	Std. Error	t value
scale(average_trust)	0.025551	0.1063	0.24028
scale(NRM_attend_code)	0.291798	0.1160	2.51481
scale(NRM_influence_code)	0.366601	0.1187	3.08772
scale(savings)	-0.180650	0.1105	-1.63417
scale(sum_gear_columns)	-0.023694	0.1155	-0.20511
scale(pca)	-0.234774	0.1233	-1.90401
scale(livsscore)	0.009221	0.1052	0.08767
scale(education)	-0.256795	0.1122	-2.28912
scale(total)	-0.044410	0.1125	-0.39472

Intercepts:

	Value	Std. Error	t value
nonelfew	-3.6898	0.3117	-11.8377
few/moderate	-1.6726	0.1450	-11.5385
moderate/many	-0.0067	0.1110	-0.0605

Residual Deviance: 759.7689

AIC: 783.7689

	Df	AIC	LRT	Pr(>Chi)	Delta_AIC
<none>	NA	783.7689	NA	NA	0.0000000
scale(total)	1	781.9245	0.155625149	0.693216700	1.8443749
scale(NRM_influence_code)	1	791.5842	9.815252604	0.001730705	-7.8152526
scale(NRM_attend_code)	1	788.1390	6.370128420	0.011605720	-4.3701284
scale(education)	1	787.0451	5.276147977	0.021619528	-3.2761480
scale(pca)	1	785.4188	3.649866046	0.056073721	-1.6498660
scale(savings)	1	784.4475	2.678571398	0.101706932	-0.6785714
scale(average_trust)	1	781.8267	0.057761108	0.810070248	1.9422389
scale(sum_gear_columns)	1	781.8110	0.042041853	0.837540014	1.9579581
scale(livsscore)	1	781.7766	0.007687343	0.930133006	1.9923127

Appendix 2 Reference List

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APPENDIX 3: Supporting Information for Chapter 5

Appendix 3.1 Survey datasheet for fishers in Andavadoaka comprising of 12 questions including (1) respondent information, (2) catch information and (3) perception of climate variability/ weather.

Interviewer Information	
Date	
Interviewer Names	
Respondent Information	
What age are you?	
What age were you when you started fishing?	
What is your primary fishing gear?	
Catch Information	
What are your main target species?	
Has the typical weight of your catch changed since you started fishing?	
What was the weight of your typical catch when you started fishing?	
What is the weight of your typical catch now?	
Have you noticed any species that are not available at present (but were abundant in the past)?	
If the respondent indicates that their catch has changed: what do you think are the main causes of the change in catch you have observed?	

<p>If the respondent indicates that their catch has changed: Have you adapted the way you fish to account for your changing catch? If yes, how?</p>	
<p>In your opinion, can you suggest potential measures or actions that can contribute to sustainable management of fisheries in Velondriake?</p>	
<p>Climate</p>	
<p>Have you notice a change in the climate/weather since you started fishing?</p>	

APPENDIX 4: Supporting Information for Chapter 6

Appendix 4.1: Abstract, Data Availability Statement and Acknowledgements for “Participatory video as a tool for co-management in coastal communities: a case study from Madagascar” *Frontiers in Human Dynamics*

Abstract: Here we examine participatory video (supporting a group to make a film around a specific issue) as a tool to facilitate input of local knowledge and empower communities in stewardship over their local marine resources. We draw from the “Voices of the Vezo” project, where researchers collaborated with a co-management partner organization and local youth to create participatory videos in traditional Vezo fishing communities in southwest Madagascar. The project focused on documenting and sharing local knowledge on shifting social-ecological conditions. Four communities participated in the project with 90 people interviewed and seven short films (7–15 min) created. The films were shared in the communities at public cinema nights and made widely available online. This paper describes the Voices of the Vezo project’s process and outputs, examines participatory video’s potential as a tool for community co-management, and outlines practical challenges and recommendations for implementing a participatory video project. We found videography to be a powerful tool for synthesizing local knowledge of shifting social and ecological conditions, especially where written records are scarce. We also identified specific examples where gathering and sharing community perceptions of marine ecosystem decline could foster discussion and action toward locally driven management interventions. Youth participants in the Voices of the Vezo project reported gaining knowledge and motivation to address marine management issues, indicating the potential for participatory video processes to cultivate local leadership. Finally, for participatory video practitioners, we found important practical considerations to help minimize biases when supporting communities with a participatory video process.

Acknowledgements: We are extremely grateful to the communities of Andavadoaka, Ampasilava, Tampolove, and Ambatomilo in southwest Madagascar for their participation in the project. We thank the youth groups for their active and enthusiastic involvement. Special thanks to Valerio Sandry, Antony Manirisoa, and Chiara Scacchetti for their help during the participatory video workshops. George Bic Manahira, your knowledge and support was greatly appreciated. We also acknowledge the support from Blue Ventures team in Andavadoaka and the helpful guidance and input of Al Harris, Matthew Judge, and Martin Muir at various stages. Finally, we extend our gratitude to the reviewers for their constructive comments which helped improve the paper.

Appendix 4.2 Extra photos demonstrating the participatory video process.



Figure A4.2.1 The stop-motion game – a game we played during the training workshops to help community participants get familiar with the camera controls.

Image: GCripps



Figure A4.2.2 A photo of participants shooting b-roll in Ambatomilo showing the camera and audio equipment provided to each group. Image: GCripps



Figure A4.2.3 Participants during the group editing stage where the filmmakers would create a storyboard of their film. Image: GCripps



Figure A4.2.4 A crowd gathered in Tampolove for a Voices of the Vezo community cinema night, showing the Voices of the Vezo film created by youth from Tampolove.

Image: ACarter