Human well-being and mangrove forests: case study on the role of coastal ecosystem services in two communities in Madagascar

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Abstract

The investigation of socio-ecological interactions involving mangrove ecosystem services (ES) illustrates the complexity of the relationships between functional ecosystems, market integration and the ability to maintain human well-being. The Belo-sur-Mer system of mangrove forests, located on the west coast of Madagascar, provides a range of ES to the communities of Antanamanimbo and Marofihitsy. Mangrove fisheries provide the majority of monetary incomes in both communities, representing 53.53 % of total annual incomes for Antanamanimbo and 59.76 % for Marofihitsy. Greater market integration in Antanamanimbo corresponds with larger material, energy and monetary throughputs. The role of mangrove ES in generating incomes is complemented by their importance as key components in local diets, communities' reliance on the mangrove as a safety-net for incomes and food production, for harvesting fuelwood and lumber, and in supporting cultural identities. Despite large differences in the size of household incomes and scale of mangrove resource extraction between these communities, their levels of human well-being are very similar. This suggests that the relationship between human well-being and natural systems is multi-dimensional and relies heavily on components that are not accounted for by the market system. Considering the role of mangrove ES in this local socio-economic context provides an invaluable tool to be used in guiding local decision making and establishing an effective balance between conservation and development.

Résumé

L'étude des interactions socio-écologiques impliquant les écoservices des mangroves (ÉS) illustrer la complexité des relations entre les écosystèmes fonctionnels, l'intégration du marché et la capacité à maintenir le bien-être humain. Le système Belo-sur-Mer de mangroves situées sur la côte ouest de l'île de Madagascar, fournit une gamme d'ÉS aux communautés d'Antanamanimbo et de Marofihitsy. La pêche dans les mangroves fournit la majorité des revenus financiers dans les deux communautés, représentant 53,53% du revenu annuel total pour les Antanamanimbo et 59,76% pour les Marofihitsy. Une plus grande intégration du marché chez les Antanamanimbo correspond à un métabolisme social plus élevé dans cette communauté, y compris des revenus plus élevés et une extraction plus intensive des ressources de la mangrove. Les ÉS de la mangrove agissent en tant que générateurs de revenus, éléments clés dans les régimes alimentaires locaux, filet de sécurité pour les revenus et la production alimentaire, source de bois de feu et de construction, et partie intégrante des identités culturelles. Malgré de grandes différences entre ces communautés dans la taille des revenus ménagers et dans l'échelle de l'extraction des ressources de la mangrove, leurs niveaux de qualité de vie humaine sont très semblables. Ceci suggère que la relation entre le bien-être humain et les systèmes naturels est multidimensionnelle et s'appuie fortement sur des facteurs qui ne sont pas pris en compte par le système du marché. Prendre compte du rôle des ÉS des mangroves dans ce contexte socio-économique local constitue un outil précieux à être utilisé dans la prise de décision et l'établissement d'un équilibre entre la conservation et le développement locale.

Extended Summary

Mangrove forests are unique ecosystems that form a link between terrestrial and marine environments. They are highly productive, and generate a large number of important goods and services that are used by coastal communities. This thesis provides a comprehensive case study on how whole communities interact with and rely upon the range of ecosystem services (ES) generated by the mangrove forests of Madagascar's west coast. It illuminates the process of market integration in rural economies, its impacts on patterns of resource extraction and communities' ability to maintain human well-being.

The theoretical background of this thesis outlines key concepts and definitions necessary to understand both the context and the importance of this case study. It discusses definitions for ES and human well-being, as well as the important linkages between these concepts. Mangrove ecosystems are described in detail with emphasis placed on their biology and outlining the ES that they provide. To understand the factors that drive resource extraction and consumption the factors of market access and social metabolism are introduced as they relate to this study of mangrove ES. The particular relevance and value of this research is explained through a comparison between performing a meta-analysis of research on mangrove ES, with an in-depth case study on human interaction with a mangrove forest.

The communities of Antanamanimbo and Marofihitsy were selected as the focus for this case study based on their geographic proximity to the same mangrove forest, similarity in size, involvement in the formation of mangrove reserves, as well as their contrasting levels of isolation and differences in primary occupation. Data collection was performed between July and September 2011 using a combination of household surveying, community focus groups and key informant interviews. The data targeted for collection fell into two main categories; one being the range of proxies representative of human well-being at a household and community level, while the other quantifies the use of various mangrove ES. Most of the material gathered on human well-being was examined through simple descriptive statistics. Reliance on mangrove ES was assessed using a combination of market prices, replacement costs and qualitative discussion of the various ES that fell outside the scope of monetary valuation.

The proxies used to describe human well-being included community demographics, educational attainment, incomes, diets, and assets owned. Antanamanimbo and Marofihitsy where shown to have nearly identical population structures that are heavily weighted towards younger age classes which suggests that they are undergoing rapid population growth. Antanamanimbo demonstrated slightly

higher levels of educational attainment, slightly better caloric and protein intake at the household level than Marofihitsy. Significant differences were found to exist in the scales of local economies between the two communities with total monetary incomes in Antanamanimbo being many times larger than those in Marofihitsy. Interestingly this difference in monetary incomes is contrasted with a reduced number of productive activities in Antanamanimbo relative to Marofihitsy.

The comparison of human-mangrove interaction focused on the benefits each community derives from mangrove ES by quantifying mangrove provisioning services that contribute to diets, incomes and shelter, and the complex cultural services related to the mangrove. Both Antanamanimbo and Marofihitsy rely on mangrove fisheries to generate the majority of household incomes. However, Antanamanimbo's greater market integration contributes to higher prices for mangrove products, as well as the harvesting and sale of a greater quantity of catches from the mangrove. In the inland community of Marofihitsy mangrove-derived resources represent nearly 100 percent of high-quality animal source protein that is essential to the nutritional quality of local diets. Antanamanimbo demonstrated a large degree of seasonality in its reliance on mangrove fisheries, with the number of households visiting the mangrove increasing substantially during the austral summer when offshore fishing is limited by poor weather.

The comparison of mangrove resource use and well-being between the two communities is supported by a discussion of the underlying factors that contribute to differences in mangrove fishery utilization by each community and how this relates to their present economic situations. The discussion then elaborates on the various factors relating to differences in human well-being between Antanamanimbo and Marofihitsy and the pathways through which they depend on mangrove ES.

This thesis is concluded by outlining a number of strengths and weaknesses found with this approach to assessing a specific set of ES at a local level. Specific attention is brought to a number of challenges that were found when attempting to apply various ES valuation techniques in the context of these two communities. Opportunities are identified for future research to expand upon the data collected in the case study and to improve the utility of ES research in its capacity to guide and inform policy makers.

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Mi saotra bevata Antanamanimbo. Mi saotra bevata Marofihitsy.

Thanks also to my family in Saskatchewan and my family in Montreal. One shaped who I am and set me on my path through this world. The other provided me with a second home and additional support on the journey.

Finally, thank you to my partner Jenna for every day that you have been a part of my life.

Mahay kely aho, fa mbola tsy ampy.

"*Without the mangrove we would all be dead.*"

-Consensus statement from Marofihitsy focus group

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1 Introduction

Over 40 percent of the world's population lives within 100 kilometres of coastlines and over half of coastal countries have between 80 to 100 percent of their population living within this area (Martínez et al., 2007). With further population growth in these areas and increasing global demand for marine products as a source of dietary protein, the reliance on marine and coastal ecosystem services (ES) is and will continue to be an essential component for maintaining human-being (Martínez et al., 2007). Tropical and subtropical marine and coastal ecosystems are facing serious threats, given the potential for increases in resource consumption by the growing human population in coastal areas of developing nations and the current patterns of resource extraction in poorer nations mostly to satisfy wealthier nations' demand.

Mangrove ecosystems occupy a key position that links terrestrial and marine systems allowing for material and energy flows that define socio-ecological interactions, and support economic and social metabolisms. Moreover, in many coastal areas mangrove forests provide the fundamental geomorphic functions that enable the creation of the physical structure of these coastal areas and allow their continued existence (Hogarth, 2007). However, many of the major drivers for mangrove ecosystem degradation are linked to their location as highly valued coastal areas are subjected to rapid growth in demand for resources (e.g. development of real estate), as well as increasing demand for mangrove related ES. For instance, by 2010 total global coverage of mangrove forests was 15 200 000 ha, declining at a rate of 0.66 percent per year, which is three to five times the overall rate of global terrestrial forest loss (Spalding et al., 2010). Furthermore, over one third of the world's historical mangrove forest cover has been removed by direct human activity (Alongi, 2002). Despite current mangrove degradation and their global contributions to human well-being, little media coverage has been given to this issue compared to that of other forest types, such as rainforest (Valiela et al., 2001).

All of the above is particularly relevant for poor coastal countries such as Madagascar, where fully functioning natural systems and direct access to coastal related ES are essential to the survival of their population; however, political instability along with extractive economic activities have severely inhibited conservation policy regarding coastal resources. Destruction of mangrove forests in coastal areas with high population density has been associated with declines in local fisheries landings, losses in coastline stability and threats to the integrity of other ecosystems, such as sedimentation of coral reefs (Giri and Muhlhausen, 2008; Laroche et al., 1997; Rakotomavo and Fromard, 2010). In Madagascar,

mangrove reforestation activities are being undertaken by local communities along with NGOs, such as The Eden Project. Considering the importance of functioning mangroves to human well-being and the high costs of reforestation efforts, it would be prudent to adopt policies and take action to prevent the destruction of these coastal forest ecosystems. Research that provides a comprehensive description of the role played by mangroves for the well-being of coastal populations is a valuable tool for policy makers and local resource users in Madagascar.

Many studies on mangrove ecosystems have attempted to investigate the relationship between ES provision at different scales (Badola et al., 2012; Barbier et al., 2011; Bouillon et al., 2008; Das and Vincent, 2009; Donato et al., 2012; Hussain and Badola, 2008; Rönnbäck et al., 2003; Sathirathai and Barbier, 2001; Spaninks and Van Beukering, 1997; Vo et al., 2012). However, these studies are limited in scope as the information provided is incomplete, focusing on individual mangroves or specific ES, but few have presented a comprehensive analysis on the full range of mangrove related ES that support human well-being (Vo et al., 2012). Furthermore, estimations regarding one ES from a specific mangrove cannot be easily nor accurately transferred to another mangrove or set of mangrove users (Vo et al., 2012). This research attempts to tackle some of these knowledge gaps by studying whole communities and the full range of interactions that local human populations have with mangrove ecosystems. This study uses a socio-ecological approach to illustrate some of the key components governing patterns of resource use and how ES maintain human well-being and economic activity is able to occur.

1.1 Aim and Objectives

The aim of this study is to illustrate the intricate relationship and the level of reliance that exist between human well-being and mangrove ES in poor coastal communities with different degrees of isolation and market access.

Objective 1: To assess patterns of resource use and levels of human well-being in two communities with different access to markets.

Although generally acceptable for decision making at a local level, monetary estimates for ES are often not transferable between communities and ecosystems (de Groot et al., 2012). Accounting and controlling for differences in socio-economic contexts including price levels, livelihoods, resource

accessibility and availability of substitutes for goods and services present challenges to the transferability of ES valuation findings that go beyond the inherent spatial heterogeneity of natural systems (de Groot et al., 2012; Ghermandi et al., 2010). The ability to perform a case study that compares two communities that have access to the same area of mangroves, yet demonstrate different socio-economic contexts and levels of well-being, will illustrate some of the issues, limitations and opportunities facing the accuracy of monetary valuation to ES.

Objective 2: To evaluate the contributions made by mangrove ES to supporting and maintaining human well-being in two communities with different access to markets.

Mangroves offer a unique range of ES that are well defined and can be easily identified in many contexts, such as provisioning services of fish and lumber. For many of these ES the fact that they can be derived only from the mangrove can give a clear geographic boundary to the source of the service and can illustrate the importance of each hectare of this ecosystem. However, given the large number of studies performed on mangrove ES there are few if any that attempt to perform a complex quantification of all the services generated by an individual mangrove system and their role in local communities (Badola et al., 2012; Barbier, 2000; Bosire et al., 2008; Gilbert and Janssen, 1998; Hussain and Badola, 2008; Rönnbäck et al., 2003; Vo et al., 2012). As values given to ES and the ability of natural systems to provide them are site specific in both spatial and temporal terms, the values estimated for one study cannot be directly translated to another mangrove system (Daily et al., 1997; de Groot et al., 2012; Vo et al., 2012). The limited transferability of local-scale services, differences in culture and economic activities, changing market prices and preferences, and the physical issue of spatial heterogeneity have all been identified as factors that illustrate the need for a comprehensive and site-specific case study of a mangrove ecosystem (Vo et al., 2012).

Objective 3: To make recommendations as to the effectiveness of using an ES approach to evaluate and manage socio-ecological interactions.

If some mangrove ES can be demonstrated to be non-substitutable in their contributions to human survival or to have value beyond price, what is the role that the values of ES should play when policy makers consider investments towards conservation or conversion of these ecosystems, such as those generated through conversion to shrimp farms or the overharvesting of timber (de Groot et al., 2012)? The limitations of ES assessments that are tied to valuation of market goods and services have been highlighted to some extent by efforts to apply values to non-market goods and services (Daily et al.,

1997; de Groot et al., 2002). However, the interrelated functioning of natural systems means that some ES are essential in the processes that generate other ES, and without a clear framework for the classification of ES the risk of double counting threatens the credibility of some monetary valuations of ES (Boyd and Banzhaf, 2007; Fisher et al., 2009). With many challenges to performing robust and accurate valuations of ES, the ES perspective for examining socio-ecological relations and patterns of resource use requires critical appraisal in order for it to be used to represent the role that natural processes play as a foundation for the existence of all life on this planet.

2 Theoretical Background

This section outlines the key concepts of ES, human well-being, a description of mangrove ecosystems and the classification of economic systems by their degree of access to markets. This material provides the theoretical background necessary to understand the academic context of this case study, as well as the choice of methodology and indicators used. It also provides an avenue for the examination of socio-ecological interactions and the driving factors behind patterns of resource consumption in developing economies.

2.1 Ecosystem Services

ES is an umbrella term used to define the natural processes that enable the resources of the planet to be maintained or converted into goods and services that human societies are able to utilize (MA, 2005b). Under the general definition of ES used by the Millennium Ecosystem Assessment (MA) there are four categories for ES classification. The first, provisioning services, refers to those that generate physical resources that may be harvested and consumed or used directly. Regulating services refer to those that maintain the environmental conditions required for continued human existence, such as climate regulation or waste decomposition. Supporting or habitat services have a broader set of implications as they act to maintain the natural systems that generate provisioning, regulating, and cultural services. Cultural services applies to the last classification of ES and accounts for the ways in which the environment enriches human well-being through intellectual and spiritual inspiration, as well as recreational experiences (MA, 2005b). This typology is generally easy to understand on a conceptual level, but it can present some issues on an operational level when the definitions are used to frame ES valuation practices.

An alternative system of ES classification aims at separating them into intermediate services, final services and benefits (Fisher et al., 2009; Fisher et al., 2008). This improved typology allows ecosystem functions and services to be broken down into complex and interrelated ecosystem processes (intermediate services), the services that they provide to humans (final services) and the impacts on human welfare that are derived through utilization of these services (benefits). When compared to the MA's original classification, intermediate services share similarities with supporting and regulating services. The final services that stem from ecosystem processes are comparable to the pathways by which regulating and provisioning services are made available for human use. As the functioning of

natural systems include multiple levels of complexity, intermediate services often interact to generate different final services, such as the combined effects of nutrient cycling, soil formation and the actions of plants that contribute to the final services of water purification and regulation of water flow (Boyd and Banzhaf, 2007; Fisher et al., 2008).

The main argument in favour of the intermediate, final service, and benefit typology is that it reduces the risk of double counting ES. Double counting is a problem that occurs when one ES contributes to the provisioning of other ES but they are quantified and accounted for individually and then aggregated in the value applied to a final provisioning service, leading to an overvaluation of the ES in question. For instance, double counting would occur if the regulating service of a mangrove's nursery effect for fish stocks is valued in addition to the value placed on fish that are caught in the vicinity of the mangrove itself. As the nursery effect contributes to the biomass and stock of fish available to be caught the value of the former should already be represented in that of the latter. The alternative typology helps avoid double counting with the definition of the benefits category, only including the ways in which ES directly impact human well-being. Following this classification the nursery effect would be considered an intermediate service that contributes to the final service of supporting and regulating fish stocks, which in turn provide the benefit of being caught and consumed by humans. In this way an ES valuation can account for the value of most of the services provided by the mangrove that are required to maintain healthy fish stocks, such as purifying water, contributing primary production, and preventing the sedimentation of reefs and other habitat, in a single, all encompassing value. Multiple benefits to human well-being that are derived from mangrove ecosystems can be added to the total assessment of the mangrove's value without overvaluing the mangrove ecosystem as the end benefits provided are independent of each other.

It is worth noting that every definition of ES is anthropocentric. They all have an end focus on how human beings use natural systems and how those uses are able to support human quality of life. While the definitions centre on the ways in which humans can exploit and derive benefits from the environment, the ES approach to socio-ecological interactions recognizes that these benefits are derived from functional natural systems rather than man-made systems (Naeem et al., 2010).

Although focused on generating benefits to humans, an ES perspective also has the potential to produce a cascade of benefits across a broader ecological web, rather than simply for our species alone. Recognizing the value of maintaining fully functioning ecosystems and their ability to create a variety of

final services and benefits through the complex interrelations of intermediate regulating and supporting services would ultimately benefit the non-human inhabitants of natural systems.

Measuring ES contributions to humans and the titling of the 'benefits' category of ES imply that all the impacts of ES on human well-being are positive. However, it should be recognized that natural ecosystem functions can also have decidedly detrimental impacts on human well-being. For instance, wetlands are now recognized as performing a wide range of highly desirable services to human populations, compared to their historical image as bogs and swamps that must be drained to become useful, such as coastal wetlands along the north coast of mainland Europe. Yet, in many cases the most 'beneficial' wetlands still have the potential to act as breeding grounds for pests and parasites, such as mosquitoes and giardia, that present themselves as having ES with negative impacts. Valuation of ES and the subsequent decisions that will be made for their governance and use must acknowledge this coexistence of beneficial and detrimental services.

This study uses a combination of both methods of classification. It recognizes the ease of defining and visualizing natural processes under the MA system and the importance of limiting the quantification of ES values to only the benefits that are directly used by humans.

2.1.1 Applying Economic Values to Ecosystem Services

The framework of the dominant economic system promotes a positive feedback loop centred on pursuing higher levels of consumption and the private accumulation of wealth and man-made capital (Ring et al., 2010). These factors have been combined to establish a paradigm in which the negative externalities generated by the extraction and use of goods and services from natural systems remain invisible in regular market transactions and policy making. This situation may be exacerbated by the goal of decoupling economic growth from the natural systems on which life and society depend (UNEP, 2011). This model for continued economic growth ignores the fundamental ecological bounds and the physical relationships within which the existence of life and society are limited. It attempts to treat the environment and ES as commodities with an unlimited propensity to supply rather than systems bound by definite limits to their productivity and ability to function (Heal, 2000). In addition, human activities can change these biophysical boundaries leading to reduced sustainable supplies of goods and services that are needed to maintain human well-being.

The complexity of ecosystem function and use is reflected in the range of methods available to quantify the values that nature provides to humans. Mainly these methods can be divided into two categories: revealed preference methods and stated preference methods (Jones-Walters and Mulder, 2009; Salles, 2011). Revealed preference methods are based on the observation of consumer behaviour and choices, and include hedonic pricing, calculating travel costs, prevention costs and shadow pricing (Kosoy et al., 2010). Stated preference methods are more explicit as they ask individuals to place monetary values on environmental goods and services through such means as willingness to pay or willingness to accept (Kosoy et al., 2010). Limitations exist for all methods of ES valuation, but some of the most notable are the difficulty of performing monetary appraisal of non-use values and the reliance of revealed preference methods and stated preference methods on questionnaires considering the inherent issues of limited participant knowledge and inaccurate answers (Jones-Walters and Mulder, 2009).

Individuals facing poverty in rural areas may be in the best positions to understand the relative importance of their local environment given the relevance of subsistence harvesting of natural resources to meet their basic material and psychological needs. However, local economic conditions could result in low monetary estimations of the values given to ES if prices in local markets are very low. Furthermore, the use of stated preference methods may help expose a strong desire for the continued existence of a natural system, but reveal that the willingness to pay for its protection is low or non-existent. In these cases, the difference between actual use value and their monetary value appraisals could be explained by the fact that households living in poverty have many other spending priorities and may face great difficulty in considering conditions under which disposable income could be spent in a manner that does not provide direct and immediate benefits to their household's survival.

The temporal scale under which ES and socio-ecological relations occur is another confounding factor that undermines the accurate valuation of ES. One example is that ongoing population growth creates the potential for greater future demands on limited resources (UNEP, 2011). If a given system has not yet reached a threshold in its functioning and ability to generate goods and services, then a valuation performed at present rates of extraction will not accurately represent the likely increase in value that could occur in the future. Decision making based on the potential value or current value of ES will have very different implications for the generation of conservation policy.

For ES that would provide benefits to society over an infinite time frame, this temporal issue creates another challenge when applying monetary valuation to ES. For instance, if a payment for ES scheme is adopted to recognize the value of the ES and promote its conservation there must be a mechanism that

accounts for the fact that these payments must occur indefinitely for the plan to work (Engel et al., 2008).

The seminal paper assessing ES by Costanza et al. (1997) estimated the then current total global monetary value of ES at USD$ 33 trillion per year. This natural benefit stream dwarfed gross national product aggregated at the global level, which was calculated to be around USD$ 18 trillion per year. Yet, even as this study's estimation was stated to fall within the wide range of USD$ 16-54 trillion per year, its authors admit that it is still an underestimation of the monetary value of ES to human society (Costanza et al., 1997). Furthermore, the majority of the values existing in the biosphere are found outside the market system, which is where most economic activity and policy decisions occur that govern resource use and human-environment interactions. Recognition of this distribution of values may lead to a shift in power relationships between stakeholders, leading to changes on how policy formation and environmental management decisions are made. Broader recognition of the fact that the majority of natural systems' values are found outside monetary market systems would lead to greater emphasis on responsible stewardship of natural systems for human well-being (Costanza et al., 1997).

Additionally, humans may place intrinsic values on natural systems to reflect the importance that these systems have in and of themselves. These may be represented by individuals' willingness-to-pay in order to support the continued existence of ecosystems without directly consuming or receiving any material benefits that ecosystems generate. However, these intrinsic values may be complemented by intermediate services, such as the filtration of drinking water by ecological processes occurring across a landscape (Vo et al., 2012). Complementarity poses a challenge when including intrinsic values in the quantification of monetary values for ES.

2.2 Human Well-being

Following the MA, human well-being has four main constituents (2005a). The first is security, including personal safety, secure resource access and security from disasters. Second is basic material for a "good" life through adequate livelihoods, sufficient nutritious food, shelter and access to goods. Third is health that encompasses the strength, feeling of wellness and access to clean air and water necessary for a "good" life. Finally, there are good social relations, which include social cohesion, mutual respect and ability to help others. The MA then places access to these factors under an umbrella of freedom of

choice and action through which individuals can pursue fulfillment of these factors in the manner that is best suited to their own interests.

The links illustrating the importance of ES in providing for human well-being are outlined by the World Health Organization's (WHO) health synthesis of the MA (MA, 2005a). Some the most significant ways in which ES support physical well-being include provision of fresh water for drinking and irrigation, production of calorically and nutritionally adequate diets, physical resources to provide shelter and clothing, medicinal products, nutrient and waste management, regulation of infectious diseases (MA, 2005a). Combining these with the broad range of human-environment interactions that can be encompassed cultural services and their importance for maintaining mental health and well-being, and overarching services, like climate regulation, that govern the very existence of life as it exists today, the importance of ES in maintaining well-being can be clearly recognized.

The MA has noted that on a global level human well-being has increased in recent years, yet this has been accompanied by a decline in 60 percent of the ES that it assessed (MA, 2005b). In order to maintain current levels of human well-being, it is predicted that over the next half-century demand for food and water will increase by 70-80 percent and 30-85 percent, respectively (MA, 2005a). Growing human populations and the associated increase in resource demand will predictably reduce natural systems' abilities to provide other ES essential to maintaining human health. Historical examples of ES overexploitation illustrate how the loss of ability to provide for human well-being has ultimately lead to the collapse of both New and Old World civilizations, notably "the agricultural-based civilizations of Mesopotamia, the Indus Valley, the Mayans and Easter Island" (MA, 2005a).

This research will use indicators for human well-being to act as proxies for communities' level of reliance on ES and the extent to which natural resource use plays a role in maintaining quality of life and survival.

2.3 Mangroves

2.3.1 Description and distribution

The term mangrove, also known as *mangals,* refers to both trees and shrubs that are able to grow in areas periodically inundated by tidal action and the habitat represented by these conditions and species (Hogarth, 2007). This means that mangroves consist of species that live under variable levels of salinity from nearly fresh water and soil to hypersaline conditions. Of those plants that live exclusively under

these conditions there are 55 species that are considered true mangroves (Hogarth, 2007). Species that are able to exist in the mangal habitat but are also found in other habitats are known as mangrove associates rather than true mangroves (Hogarth, 2007).

Perhaps the most significant factor in identifying mangrove species and habitats is the condition of constantly waterlogged soils and the plants' corresponding phenological adaptations. Structural adaptations to survive under these conditions represent some of the more visually recognizable features of mangrove species. These include the distinctive arching aerial roots of *Rhizophora* species, the striking masses of columnar pneumatophores growing from *Avicennia* and the more subtle undulations of *Bruguiera* and *Xylocarpus* that rise out of the surrounding sediment (Hogarth, 2007). All of these features have evolved to provide oxygenation to submerged roots by way of air flow through surface openings called lenticels and internal airways called aerenchyma.

Mangroves are found along tropical and subtropical coastlines, with their range generally limited to regions with minimum winter ocean temperatures of 20°C (Hogarth, 2007). The limiting factor of ocean temperature allows mangroves' range to extend into temperate zones in areas with warm prevailing currents such as the eastern coasts of Australia and South America. Similarly, mangroves are limited in part by the cold Humboldt Current on South America's Pacific coast and the Benguela Current along the southwest coast of Africa.

At the local level, mangroves are restricted to sheltered intertidal areas and their distribution is shaped by factors such as shore morphology, salinity, sedimentation, tidal and river flow (Hogarth, 2007). Many of the largest areas of mangrove forests are found around fringing channels of major river deltas where saline water is able to penetrate the fresh water outflow. Tidal-dominated estuaries and lagoons may present the opportunity for sediment accumulation and generation of shallow and sheltered intertidal areas favourable to mangrove growth (Hogarth, 2007). Sediment deposition from rivers and high levels of wave action may create barrier islands or sand spits that afford the shelter necessary for mangrove formation. In cases of fringing mangroves the landward side of the forest is provided shelter by its outer fringe and accumulated sediment. This situation can create a wide area occupied by what is known as interior mangroves (Hogarth, 2007).

Even when sheltered from waves and currents, interior mangroves must often endure variable levels of salinity. High rainfall and groundwater flow can lower salinity, while evaporation of seawater and evapotranspiration by the mangroves themselves can contribute to hypersaline conditions at the

mangroves' roots (Hogarth, 2007). Some species of mangrove can survive soil salinity exceeding 65 parts per thousand, relative to seawater at approximately 35 parts per thousand (Smith, 1992).

Mangroves endure salinity through combinations of exclusion, tolerance and secretion of sodium and chloride ions (Hogarth, 2007). Exclusion of salt occurs at the root surface and is an adaptation used by most mangrove species. In addition, or instead of exclusion some species will actively secrete excess salt through salt glands in their leaves or by depositing salt in their bark (Hutchings and Saenger, 1987). The species that excrete salt through their leaves often have visible salt crystals on their foliage, particularly on the lower surface of the leaves. A number of species will deposit salt in older leaves which have lower photosynthetic ability and eventually shed these leaves along with their load of excess salt. In spite of these many methods of reducing salt concentrations in their tissues nearly all mangrove species must also present a high level of salt tolerance when compared to most other terrestrial plants.

These processes of obtaining and maintaining supplies of fresh water within the plant while excluding salt are energy intensive (Hogarth, 2007). This places a strain on mangroves that contributes to dwarfing of the plants under particularly adverse conditions (Hogarth, 2007). Even under favourable conditions mangroves have a high root/shoot ratio, as a large root biomass is required for water uptake (Hogarth, 2007). Mangroves also attempt to maintain high levels of water efficiency during photosynthesis through reducing stomatal conductance and lowering the need for evapotranspiration by having leaves grow at an angle relative to incident light to reduce solar heat gain (Hogarth, 2007).

Individual species of mangrove usually have different levels of tolerance to factors such as root inundation and waterlogged soil, or salinity and limited fresh water. Spatial variability in these factors tends to result in species distribution gradients across tidal ranges as individual species thrive where they are best adapted to endure the local combination of stressors. Combined with patterns of propagule distribution and ecological succession, this contributes to distinct species zoning, often leading to monospecific areas within the mangrove forest (Smith, 1992). This spatial heterogeneity of mangrove forests contributes to local variability in their ability to generate particular bundles of ES.

2.3.2 Mangrove Ecosystem Functions

Located in the transitional zone that links marine and terrestrial systems, mangroves are able to generate a unique range of goods and services. Mangrove forests are able to perform photosynthesis more efficiently than submerged plants or algae (Hogarth, 2007). This has two major impacts: one being

the capture and storage of atmospheric carbon, and the other being the contribution of biomass produced by photosynthesis in the mangrove to distant marine food webs.

Mangroves can exhibit a high rate of carbon fixation per hectare. This process occurs two ways: the sequestering of carbon into plant biomass and the trapping of sediments by the mangrove root system(Bouillon et al., 2008). However, the rates of carbon storage plateau as mangroves reach maturity, similar to terrestrial forests, with carbon flows becoming nearly balanced (Alongi, 2011; Bouillon et al., 2008).

The ability to trap and store sediment from rivers, runoff waters, and shoreline erosion makes mangroves crucial in reducing the sedimentation of coral reefs. Similarly, the capture and utilization of excess nutrients from terrestrial runoff can reduce nutrient loading in coastal waters, lowering the impacts and likelihood of algal blooms that could smother reefs or contribute to marine dead zones (Kühlmann, 1988).

From a fisheries perspective the impacts of mangroves can be considered akin to the annual flooding of tropical rivers, such as the Amazon. In these freshwater systems, flooding expands the river to encompass wide areas of terrestrial forest, allowing aquatic organisms to access vast resources, such as food and shelter amongst the trees. In mangrove forests flooding happens twice-daily with each incoming tide. In this way grazers and juvenile fish are able to benefit from the high photosynthetic productivity of the mangrove by feeding directly upon the material produced by the mangrove plants and detritus found within the mangrove. Biologists have divided fish populations that utilize mangroves into five general classifications (Robertson and Duke, 1990). The first four classes interact directly with the mangrove habitat as either permanent residents, temporary long-term or seasonal residents, temporary short-term or sporadic residents, or through association with the mangrove during one or more stages of their life cycle, such as juveniles of some species using the mangrove for feeding and shelter (Robertson and Duke, 1990). The fifth class of association is indirect and encompasses species that consume biomass produced or captured in the mangrove after it is transported into other marine habitats by species from the first four classes (Walters et al., 2008). This classification illustrates some of the pathways through which mangrove forests contribute to fisheries that exist outside the physical boundaries of the mangroves themselves.

The relationship between mangroves and aquaculture is also very complex. Mangroves are naturally able to support diverse and productive populations of commercially valuable species that humans have

used in the practice of aquasilviculture (Primavera, 2000). In addition, the shallow and sheltered areas naturally colonized by mangroves are often ideal locations for shrimp aquaculture installations, which can promote mangrove deforestation, pollution and disruption of ecological processes. It is worth noting that many shrimp aquaculture operations are reliant on wild eggs and larvae to produce shrimp, or a supply of mature female shrimp to maintain hatchery populations and their genetic diversity (Primavera, 1998b; Walters et al., 2008). In turn, these stocks of eggs are dependent on the functioning of natural mangrove ecosystems that support wild shrimp populations (Rönnbäck et al., 2003; Walters et al., 2008).

Aside from fin and shellfish, a wide range of forest goods may also be harvested from mangroves. These include fuel wood, lumber, medicinal plants and tannins used for colouring and preserving wood and other materials (Walters et al., 2008). These goods are complemented by a number of other services including a mangrove forest's ability to reduce the impact and damage from storms in coastal areas.

Some of the monetary contributions to human societies by mangrove forests that are mentioned in this section are illustrated in **Error! Reference source not found.**. These monetary figures demonstrate both he wide range of services that can be supplied by coastal wetland biomes and the diversity in the values that are attributed to them.

Table 1 Summary of mean monetary values for ES generated by coastal wetland biomes, including mangroves, tidal marsh and salt water wetlands (values in Int.USD$/ha/year, 2007 price levels). Data from de Groot *et al.* (2012).

Ecosystem service	**Values**
Provisioning services	2998
Food	1111
Water	1217
Raw materials	358
Genetic resources	10
Medicinal resources	301
Regulating services	171 515
Climate regulation	65
Disturbance moderation	5351
Waste treatment	162 125
Erosion prevention	3929
Nutrient cycling	45
Supporting services	17 138
Nursery services	10 648
Genetic diversity	6490
Cultural services	2193
Recreation	2193
Total monetary value	**193 845**

2.4 Market Integration and Social Metabolism

According to United Nations Development Programme's Human Development Index, Madagascar is ranked 151 out of 187 countries (UNDP, 2011). In remote areas of Madagascar many communities face high levels of poverty and limited options for economic development. However, this does not mean that economic activity is absent in these areas. Rather, when comparing resource use and market activity between communities, small differences in market access and integration may lead to large changes in socio-ecological characteristics.

The comparison of market activities between communities that are closely linked to natural systems requires a set of definitions that will help differentiate between levels of market access and specialization in productive activities. Given the complexity of customary patterns of local resource use and human propensity for ingenuity in order to meet basic needs and provide for well-being, a system of economic classification based on communities being more or less 'developed' would not only be inaccurate for depicting local living conditions, but also not a depiction of the communities socio-ecological history. Rather than use the typology of 'development' to compare economic activity, it has been deemed more prudent to compare communities based on the extent and manner of their integration into market systems and each community's social metabolism as it relates to mangrove resource use (Altman, 2005; Altman, 2007; Busilacchi et al., 2012; Fischer-Kowalski, 2011; Fischer-Kowalski et al., 1997; Haberl et al., 2011; Sieferle, 1997). Within the framework of market integration and social metabolism, communities' reliance on provisioning services in both subsistence and commercial capacities can illustrate the connection between ecological and economic systems, and the role of the environment in promoting well-being (Fischer-Kowalski et al., 2011).

2.4.1 Market Integration and Specialization

In the context of this study, market integration relates to the manner in which market exchanges occur and the scale or distance over which these transactions take place. Isolation implies a reduced level of market integration by reducing the number and frequency of opportunities for exchanging goods and services, or increasing transportation and transaction costs. Communities with lower levels of market integration have limited access to goods and services that cannot be, or are not, produced locally. In some cases, this means that isolated communities must forgo some of the benefits of market efficiency and consumption. A low level of market integration may also contribute to communities' pursuit of

customary activities rather than focusing on productive activities with the largest profit margin (Singh et al., 2001). Customary activities include the harvesting of non-market goods through activities such as fishing and farming at a subsistence level (Altman, 2005; Altman, 2007). However, the term 'customary activities' does not simply refer to resource extraction occurring at a small scale and for direct consumption, but it goes further in recognizing that these activities are also part of local traditions that may refer to particular styles of artisanal fishing or farming practices that generate cultural, as well as material benefits.

Specialization of productive activities, according to neoclassical economic theory, is characterized by individuals or communities limiting the range of productive activities to those areas with the largest margin of profit. Specialization is intended to improve economic efficiency by encouraging parties to focus their efforts on those activities where they have comparative advantages in production, and limit effort spent on those activities where other parties are more efficient (Ricardo, 1817). When combined with market integration, individuals can trade the fruits of their labour for goods and services generated by others who are acting in their respective fields of comparative advantage. As a result, all parties are considered to have the option of increasing personal consumption above the levels that are possible with access to only their own productive activities (Daly, 1993).

The processes of market integration and specialization of productive activities encourage commoditisation and monetization as goods and services are valued for exchange (Kosoy and Corbera, 2010; Polanyi, 2001). Monetization refers to the manner in which the values of production and exchange are accounted for. In a formal market system commodities are exchanged for money, which may then itself be exchanged again for another commodity in a commodity-money-commodity pattern of exchange (Gregory, 1997). Money is recognized as having an official value beyond its physical utility (Soddy, 1933). This allows the producers of goods and services to capture and accumulate the value of their products in a non-perishable form as money. In a formal market system, money may be used to purchase goods that are available at a low price at a particular place and time, and then resell the same goods at a different time or location when or where the price is higher. A further impact from this practice is that it encourages greater market integration by offering a means to compensate and provide incentive to parties that are able to transport goods and deliver services among locations in response to price differences that result from variability in comparative advantages. By taking advantage of these spatial and temporal price differences, and by accumulating the value of goods and services in a non-

perishable form, individuals are able to gain access to products with values that exceed what individuals would be able to generate through their own labour.

When market exchanges are limited to a local scale where parties know and trust one another, transport distances are limited and time does not have a significant impact on the value of perishable goods, a kind for kind system of barter is possible and potentially practical for managing exchanges. At low levels of market integration there may be a combination of the above mentioned commodity – money – commodity exchange system with a commodity – commodity barter system (Gregory, 1997).

However, when specialization of productive activities occurs, individual parties reduce the range of goods and services that they generate. A party that produces only a single type of good or service, for example coconuts, may find that the other producers in the market, from which they need to purchase essential goods and services, do not have a constant or uniform need for coconuts that matches the coconut producer's need to buy other goods. In this case money represents a means to convert the value that a small number of players in the market place on coconuts into a form that has extended usefulness to all players regardless of their need for coconuts. However, the lack of variety in the coconut producer's economic portfolio leaves this individual vulnerable to changes in the market value for coconuts. This means that such individuals are in a position where their livelihood is less resilient to shocks relative to those who have maintained a diverse range of productive activities despite lower levels of efficiency in production.

The classification used in this study recognizes the impossibility of a community existing in a purely subsistence context. Even if unintended, eventually or occasionally, a surplus will be generated and may be exchanged for goods not produced by the individual party. As communities in rural Madagascar are not usually centers for the industrial manufacturing of consumer goods, populations in these areas are dependent on importing material goods that allow them to enhance their own productive capacities or otherwise improve their ability to meet basic needs and support well-being (Bashaasha et al., 2006; Mutenje et al., 2010; Takasaki et al., 2000; Wamani et al., 2004). Therefore, market integration offers an avenue for enhancing human well-being by improving access to and increasing the consumption of material goods and services. Following this pattern of production and consumption, it can be predicted that in two communities with the same potential for production, higher levels of well-being will exist in the community that has a higher level of market integration, allowing better access to and higher consumption of material goods than a community that has lower market integration and less opportunities for exchange.

2.4.2 Social Metabolism

The concept of a social metabolism is based on the idea that social systems exist in a state with constant material and energy exchanges occurring between the society and the natural environment in which it exists, as well as with other social groups, and that these flows can be quantified per person per unit of time (Fischer-Kowalski and Swilling, 2011; Fischer-Kowalski et al., 2011; Haberl et al., 2011). This stems from the theory of sociometabolic regimes, where human systems of subsistence and production can be classified based on their primary sources of energy and energy conversion technology (Fischer-Kowalski et al., 2011; Sieferle, 1997). This classification system follows the course of human societal development from the passive collection of solar energy through hunting and gathering, to active collection and use of solar energy through selective agriculture, and to industrial regimes where energy use has expanded beyond a reliance on current biophysical production to the utilization of historical solar energy stored in fossil fuels or the capture of energy from other non-biological sources (Fischer-Kowalski et al., 2011; Sieferle, 1997).

The metabolism of a particular community can be used to quantify its relation to and reliance upon natural systems by measuring the inflows of energy and materials, as well as the outflows, including the emission of wastes back into the natural system. This can be used to compare environmental impacts among communities, or within an individual community as it develops and transitions between metabolic regimes over time (Fischer-Kowalski et al., 2011)

When considered in reference to the theory of social metabolisms, market integration and associated increases in well-being can result in large increases in the use of energy and material by a community (Haberl et al., 2011). This can be interpreted as increasing the community's metabolic rate and therefore increasing its impact on the environment through the harvesting of resources and the emission of wastes.

For this study that investigates human reliance on mangrove ES, the scale of market exchanges and resource extraction can serve as proxies for measuring market integration and communities' social metabolism. Market integration indicates the community's access to material goods and services that in turn may improve quality of life. At the same time the connection between resource exchange, energy use, market activity and social metabolism can indicate the impacts that communities have on natural systems and the pathways through which societies rely on specific ES.

2.5 Case Study on Mangrove Ecosystem Services

Having illustrated the many links between ES and human well-being in a variety of contexts, and that mangroves are unique and complex ecosystems capable of providing many important benefits to human populations, it can be understood that responsible management and conservation of mangrove ecosystems should be a focus for policy makers. However, as mentioned above, the ES generated by a particular ecosystem have associated values that are temporally and spatially specific (Vo et al., 2012). In order to deliver effective and responsible policies to govern the use of natural resources, accurate information must be made available to illustrate the full range of benefits that mangroves provide to those who interact with them. By means of a case study approach we will investigate the ES generated by a single mangrove ecosystem and the role that these ES play in supporting human well-being in local communities.

Many studies have investigated specific ES generated by mangroves (Donato et al., 2012; Hussain and Badola, 2008; Kathiresan and Rajendran, 2005; Mumby et al., 2004; Rönnbäck, 1999a; Thu and Populus, 2007). These studies have been compiled under meta-analyses that attempted to aggregate the values represented by various mangrove ES into a form that should generally represent benefits derived out of any mangrove ecosystem (Vo et al., 2012; Walters et al., 2008) . However, given the locally and temporally specific nature of ES it is surprising to note the lack of comprehensive studies performed to verify the range of mangrove ES generated through a specific mangrove forest and its contribution to local economies.

A case study that investigates the direct benefits that mangroves provide on a local scale will not only assess the validity of monetary values, but it will also help translate how a plurality of values relates to the immediate well-being and resource-use decisions made by those who interact with these ecosystems on a regular basis (de Groot et al., 2012; Vo et al., 2012).

3 Methodology

This section presents the methods and analysis used for this case study. It provides an outline of the site selection process used to identify appropriate locations for this case study and a description of the selected study sites. This section then goes on to communicate the choices made in data collection and analysis.

3.1 Site Selection

The study sites were selected based on a range of social, geographical and ecological criteria that are described in the following paragraphs.

Estimated community size was used to select villages that had similar numbers of inhabitants, to ensure that potential local demand for and personal consumption of resources from the mangrove would be comparable. It was also desirable to select communities with relatively small population sizes, to allow a more accurate quantification of economic activities and resource flows within and between communities, and external markets. Surveying in a small community could be undertaken along the lines of census that would be more difficult to perform in a larger community due the time and effort required, and the complexity resulting from the more diverse range of economic activities that would be possible with a larger pool of labour.

Geographic and ecological similarities between study sites were ensured by selecting communities that border and make use of the same mangrove complex. This guaranteed that each community had the same or similar opportunities to access resources from the mangrove and would reduce the impacts of habitat heterogeneity on ES utilization (de Groot et al., 2012; Vo et al., 2012). As a result, there should be similar or identical species composition, and primary productivity in the mangrove area that is being used by each community. For the selected study sites, distance from the mangrove was also similar to reduce the impact of travel time and resource accessibility on differences in mangrove interaction between communities (Ghermandi et al., 2010). Additionally, multiple communities in this region have been involved in the establishment of temporary protected areas within the mangrove with the location, harvest restrictions, and length of reserve status being decided upon by community members. Closure of the reserves occurred not long before household surveying was conducted and it can be assumed that recent involvement in this process would contribute to community members being relatively well informed on the subject of local human-mangrove interactions at the time of this study.

To ensure that a comparison could be made between contrasting patterns of resource use in this case study it was necessary that the selected communities differed from one another in a number of ways. These differences included the dominant cultural groups or cultural identity in each community, which would ensure different social or cultural perspectives on their relations to the mangrove ecosystem. In this area material standard of living, primary occupation and general lifestyle were also predicted to differ between study sites that could be divided by dominant cultural groups. Furthermore, the communities to be selected had different levels of physical accessibility or isolation, with corresponding influences on market activity, capital flows, and resource access.

3.1.1 Sites

These study sites are located in Belo-sur-Mer Rural Commune of the Morondava District of Madagascar's Menabe region. Artisanal fishing is the primary industry in coastal villages in this area. However, other industries in the region include tourism, the construction of wooden sailing vessels known as *boutry* in Belo-sur-Mer and the production of salt in the village of Antsira. The dominant industry in inland communities is agriculture.

The Belo-sur-Mer mangrove complex consists of a series of interconnected, mangrove-dominated lagoons in the vicinity of Belo-sur-Mer, Madagascar. Both communities identified as study sites are adjacent to and interact with this mangrove forest.

Antanamanimbo

Antanamanimbo is located on a narrow sandbar on the seaward side of the lagoon where the mangrove is found (see Figure 1). From this location fishers have access to fishing in the Mozambique Channel to the west and to the lagoon and mangroves to the east. The community stretches over three kilometres of coast. The distance between houses and the edge of the mangrove vary from less than fifty metres to nearly one kilometre. The population of Antanamanimbo belongs to the Vezo cultural group. The Vezo are semi-nomadic, artisanal fishers that can be found along the west coast of Madagascar (Cripps, 2009). They typically travel by means of *laka*, a dugout canoe of varying size fitted with a single outrigger, often also using a square sail. Fishing near shore is also performed using a *molonga*, a smaller dugout canoe, normally lacking the outrigger.

Marofihitsy

The village of Marofihitsy is located in a clearing in the arid spiny forest approximately two kilometres inland from the nearest mangrove forest (see Figure 1). This distance is consists of about one kilometre of dry forest and one kilometre of tidal salt flat on the landward side of the mangrove complex. The population of Marofihitsy is considered to be composed largely of members of the Masikoro cultural group. The Masikoro are predominately smallholder farmers who practice slash and burn agriculture in the dry deciduous forest of Western Madagascar.

Resident populations in these two communities were essentially the same at the time of surveying, with each community being composed of approximately 200 people. In Antanamanimbo, 33 households were surveyed accounting for a total of 187 individuals. In Marofihitsy, 37 households were surveyed accounting for 190 individuals.

Figure 1 : Map showing the location of study site communities Antanamanimbo and Marofihitsy, as well as the mangrove forest that is accessed by both communities (adapted from Google Earth, 2012).

Mangrove Forest

The mangrove forest that is utilized by the communities in this case study extends for approximately 14 kilometres and has a maximum width of about four kilometres. It is divided into two tide dominated lagoons that are connected at high tide. Extensive salt flats are present on the landward side of the mangrove and the forest itself is divided by many tidal channels and pools. Species of trees identified as present in this mangrove include: *Ceriops tagal* (TANGAMBAVY), *Rhizophora mucronata* (TANGANDAHY), *Bruguiera gymnorrhiza* (TANGAMPOLY), *Xylocarpus granatum* (FOBO), *Sonneratia alba* (SONGERY), *Lumnitzora racemosa* (ROGNO), and *Avicennia marina* (AFIAFY).

3.2 Household Surveying and Focus Groups

For both Antanamanimbo and Marofihitsy, household surveys were used to investigate socioeconomic conditions, human well-being and household-mangrove interaction in both quantitative and qualitative terms. The proxies of well-being that were investigated, their predicted relations to various mangrove ES, and corresponding influences quality of life are outlined in Table 2.

Table 2 : Summary of the proxies for human well-being considered in this study and their relations to mangrove ES services in the context of coastal Madagascar

Proxies of Well-being	Relation to ES
Diet : Calories Protein Food Security	-The proportion of calories and dietary protein derived from the mangrove indicates the relative importance of the provisioning services of mangrove fisheries -Seasonal changes in food security may indicate variation in the level of importance of mangrove ES as a dietary safety net
Formal Education: Literacy Years in school	-Although not a direct indicator of particular ES, receiving formal education can provide individuals with the opportunity to pursue livelihoods other than the subsistence harvesting of natural resources
Income: Amount Source	-The proportion of household income derived from the sale of mangrove-derived products is a direct indicator of the monetary value of provisioning services and their relative importance in the acquisition of other goods and services
Shelter: Type and source of materials Cost to replace	-The value of lumber and fuelwood provisioned by the mangrove can be quantified in terms of money and labour required to construct shelter -The regulating service of shelter from storms may also be interpreted through comparisons of property damage in areas with and without protection by mangroves
Spiritual	-The cultural services provided by the mangrove ecosystem are illustrated by the religious importance and intrinsic values attributed to them by local populations

Identical surveys were used in each community to ensure comparability in results pertaining to household levels of human well-being. The survey was designed using the World Bank's guide 'Designing Household Survey Questionnaires for Developing Countries' (World Bank, 2000). The contextual suitability of questions was assessed through involvement of local key informants in the survey writing process. These informants ensured that the questions would be acceptable in the cultural context of the selected communities, that they would be understandable to participants, and that they would generate appropriate responses to allow a detailed investigation of household-mangrove interaction. Surveying was performed through a practiced translator who was fluent in the local Malagasy dialect; each survey took approximately 45 minutes to complete.

Focus groups were used to investigate community level perspectives on resource use and mangrove interaction. Focus group questions were used to gather information on group values for the mangrove ecosystem, to explain communal perceptions towards cultural role of mangroves and to further illuminate points of interest that were identified during household surveying .

Key informant interviews were used to collect material where individuals would possess specific knowledge on topics that may not be common throughout the community. These included interviews with individuals involved in specific trading networks, those practicing particular methods of fishing, with unique cultural values relating to the mangrove, and parents to determine their perspective on the role that they see for the mangrove in the lives of their children.

Participation

In Antanamanimbo every household that had at least one adult member present in the community during the study period was surveyed, with the exception of three households that were not surveyed because household members were unwilling to participate or that they demanded payment in exchange for their participation. An unknown number of households were not surveyed in Marofihitsy at the time of the study. This was due to the practice of families moving into the forest to tend and guard their garden plots for extended periods of time. However, as a funeral for an elder from Marofihitsy occurred in the community during the study period, it is likely that many of these families were present in the village at this time to take part in the funeral ceremony and therefore were included in surveying.

Focus group participation was based on composing a group of individuals that represented the range of age groups, genders and occupations present in each community. When questioned, the focus groups were asked to consider the views of the community as a whole and then respond accordingly. Individual

responses were verified with the rest of the focus group and additions to each response were solicited from the group.

3.2.1 Human well-being

Human well-being was assessed through survey questions focusing on demographics, education, incomes, diets and non-dietary components to material standard of living.

Demographics and educational attainment comprised the first section of the survey. Age, gender and number of individuals per household were used to estimate total population sizes, age structure and other population characteristics such as population growth and trends. Educational attainment was investigated by establishing the number of years of schooling achieved by each household member and whether or not the individuals were literate. These values were used to estimate the percentage of the population with formal education and the level of literacy for both adults and youths. Literacy was also broken down and compared between communities in terms of number of households with at least one member with literacy.

Diets were investigated through questions on the different sources and quantities of proteins and carbohydrate staples consumed by the household on a weekly basis. Fruits and vegetables were not given a large focus in this portion of the study as during the study period fruits and vegetables only make a minor contribution to diets in this area. Units of staples and protein were converted from local units, *kopoake* (a scoop about 250 millilitres in size) and *toko* (a small pile, stack or group), to kilograms consumed per individual. Dietary protein and caloric content were then calculated using FAO regional standard values for each of the foods indicated as being consumed by the household (FAO, 1968). Given the very high variability found in weekly levels of consumption for different types of food the quantities consumed have been divided into ranges of values in order to calculate the modes for the caloric and protein content of local diets. Respondents were also asked to identify during which, if any, months of the year any members of their household went hungry or faced levels of food insecurity.

Questions on income began by identifying the primary occupations of household members based on time spent performing productive activities and through their perceived primary and secondary sources of incomes. This was followed by identifying all sources of monthly income, as well as any other major sources of income that may occur on an annual basis, such as the sale of livestock or the construction and sale of a *laka*. Focus was placed on the participation of household members in agricultural activities

and participation in fishing activities, as these were identified as the primary areas of productive activity during pre-survey consultations. Further questions were asked to investigate the context in which market exchanges occurred for each household in order to identify the distances to various markets and differences in prices received for goods. Local prices received or paid by each household for goods and services in the community where determined during surveying.

Material standard of living was assessed through questions on assets owned by the household, as well as considering the construction and condition of the home itself. Specific assets considered were ownership of valuable fishing equipment such as boats or shark nets, zebu carts or plows, generators, flashlights, radios. Homes were evaluated on the material used, manner of their construction, cost to rebuild, and the sources of lighting and cooking. A visual, rapid rural appraisal was also performed during surveying to make general comparisons between living conditions in Marofihitsy and Antanamanimbo (Takasaki et al., 2000). Levels of hygiene were assessed using questions on household access to soap and ranking the number of flies present around the home as part of the rapid rural appraisal.

3.2.2 Household-Mangrove Interaction

Interaction between household members and the mangrove were investigated on a number of levels. Households were asked how often and how many people visited the mangrove on a weekly basis. They were also asked to identify during which months of the year members of their household visit the mangrove. The purposes of these trips were also recorded to determine whether the mangrove was being used for fishing, fuel or lumber collection, recreation, religious or other purposes and the frequency of visits for each of these purposes.

The primary area of interaction investigated was mangrove-fisheries linkages. General fishing locations were established to determine whether catches where made in or near to the mangrove. Participants were asked to identify how often their household fished in the mangrove, what species and how much of each they caught in an average week. For catches from the mangrove they were then asked how much of their catch they consumed, how much was sold and at what price during an average week. These questions on catch, household consumption and sales were also asked for weeks with good and bad catches to establish the range of catches that occur on a weekly basis and attempt to account for any seasonal variation that may exist in fishing effort and levels of success. The portions of catches from

the mangrove consumed by each household were compared to household caloric and protein intakes to determine the contribution made by the mangroves to diets in both communities. The sales of catches from the mangrove were compared to total household incomes to establish the monetary value of the mangrove in each village's economy.

As the fishery for the mud crab (*Scylla serrata*) was identified during pre-survey consultations as being of particular economic importance in this region further questions were asked regarding the catches of this species. These questions included gathering information as to the manner in which crabs are caught, stored and sold; if and how the crab fishery is regulated; and what prices are received for the crabs in various markets. This was complemented by a biophysical analysis of 182 live crabs that were caught in the Belo-sur-Mer mangrove complex to determine the biophysical characteristics of crabs being caught in this area. The characteristics analysed included the sex, weight and carapace width of the crabs caught, as well as grouping them into *toko*s in order to determine a mean weight for when this local unit of measure is being applied to crabs.

Attempts were made to quantify other material resources harvested from the mangrove in the form of lumber and fuel-wood collected from the mangrove by asking about the number of trips per week and quantity of wood collected per trip. This was complemented by visual and survey assessment of home construction style and materials that was used to determine the mangrove's role in providing shelter for each household. The cost to build a standard new home in each community was determined through key informant interviews and focus groups to establish a monetary value for lumber harvested from the mangrove that is used in construction and providing shelter.

This area of Madagascar was in the direct path of cyclone Fanele in 2009, which caused severe damage including the destruction of several brick buildings in Belo-sur-Mer. The positioning of the two communities relative to the mangrove and the path of Fanele, is such that Antanamanimbo which is seaward was unsheltered by the mangrove versus Marofihitsy which was inland and may have been sheltered from the mangrove; this encouraged investigation into whether or not the mangrove was able to mitigate the effects of the storm. Survey participants in both communities were asked to identify whether their home was destroyed, heavily damaged, lightly damaged or undamaged by the cyclone. When combined with the cost to rebuild a home in each community, and whether building materials were harvested from the mangrove, this material can indicate the local role of the mangrove in providing shelter and resilience in the face of major storm events.

The intrinsic values placed on the mangrove were assessed qualitatively and quantitatively through the surveys and focus groups. Spiritual and religious uses of mangroves were investigated by asking whether household members placed a spiritual importance on the mangrove, determining the proportions of each community's population that placed this type of value on the mangrove. They were then asked an open-ended question as to why the mangrove held spiritual importance for themselves and other household or community members. They were also asked whether or not members of their household placed importance on the mangrove for any non-use reasons. Non-use values were addressed with questions on households' personal non-use values for resources from the mangrove and the perceived implications of each community's total restriction from accessing mangrove resources. Exercises were attempted to determine the communities' willingness-to-pay for mangrove conservation or willingness-to-accept in compensation for the destruction of the mangroves; however, these were largely unsuccessful. In focus groups and key informant interviews questions were asked relating to the views that each community had regarding their children and how they should see the mangrove and whether it was important for their children to know the mangrove and value its existence.

3.3 Data Analysis

The data analysed in this case study falls into two main categories; one being a range of proxies that are representative of human well-being at a household and community level, while the other is related to quantifying the use of various mangrove ES.

Data collected from household surveying was analysed using descriptive statistics to compare responses between the two communities. These descriptive statistics were used to determine the percentage of each population with access to various resources and their relative living conditions, basic demographic and educational data, and to compare household responses regarding cultural services provided by the mangrove. Where applicable, t-tests were used to test for significant differences between mean values for household incomes, quantity and composition of diets, and the landings of marine resources from the mangrove in each community. Significant differences between mean values for household incomes, catches, and diets were assessed on a 95 percent confidence interval. The distribution of survey results around their mean values are displayed using modified boxplots, which illustrate outliers in each dataset.

Landings for crabs and fish were calculated based on total reported weekly landings and reported weekly landings from the mangrove. Annual landings were calculated through the extrapolation of reported normal weekly landings for different species in combination with each household's response regarding seasonal patterns in fishing practices.

The calculated monthly incomes for each community were based on reported monthly household incomes from various sources. The major income sources (the sale of fish and crabs) were verified by cross-checking reported monthly monetary income with maximum, minimum, and normal kilograms landed for individual species along with the portion of catches sold and price received per kilogram.

Reliance on mangrove ES was assessed using a combination of market pricing for resources harvested from the mangrove, calculating replacement costs and qualitative discussion of the various services that fall outside the scope of monetary valuation.

4 Community Comparison

To investigate and compare the interaction with and use of mangroves between two communities and economic systems it is necessary to determine the status of well-being in both communities and in what areas well-being differs between them in order to compare the role of resource use between the two groups. Having outlined differences in living conditions and human well-being between Antanamanimbo and Marofihitsy it then becomes possible to investigate how well-being in these communities is supported by the utilization of mangrove ES.

Sections 4.1-4.3 outline the results relating to basic measures of human well-being and to the general situation of life in these two communities.

Sections 4.4-4.6 contain the results that pertain to mangrove-derived ecosystem service use by Antanamanimbo and Marofihitsy.

4.1 Isolation and Market Integration

In this case study the communities of Antanamanimbo and Marofihitsy can be differentiated based on their level of market integration and the level of specialization in productive activities at a community scale.

4.1.1 Isolation

Given the location of Antanamanimbo on the seaward side of the Belo-sur-Mer mangrove complex, this community has relatively easy access to maritime traffic and trade. Sous-collectors who will purchase crabs, dried fish and other products visit the community on a semi-regular basis. Alternatively, community members have the option of sailing approximately seven kilometres north to Belo-sur-Mer (see Figure 2). In Belo-sur-Mer there is a larger local market for fisher's catches and the sous-collectors stop with greater frequency. Some of the fisher's from Antanamanimbo will also purchase catches from their community and sail over 60 kilometres north to the city of Morondava, thereby bypassing the sous-collectors and accessing higher prices for their goods. Breakdown of prices for various fishery products is presented in Section 4.5.3 Mangrove Contribution to Incomes.

Marofihitsy does not have direct access to maritime transportation. The nearest community presenting a larger market for their produce is Belo-sur-Mer. The distance between communities is 14 kilometres along a dirt track that is usually travelled on foot or by zebu-cart (ox-cart). Inland trade occurs with villages described as being at least as far as 12 hours away in one direction when travelling by zebu-cart. Only one household indicated trading with villages inland on behalf of Marofihitsy. Other members of the community mentioned occasionally travelling to Belo-sur-Mer to sell produce, livestock or crabs, but that this does not occur on regularly scheduled intervals.

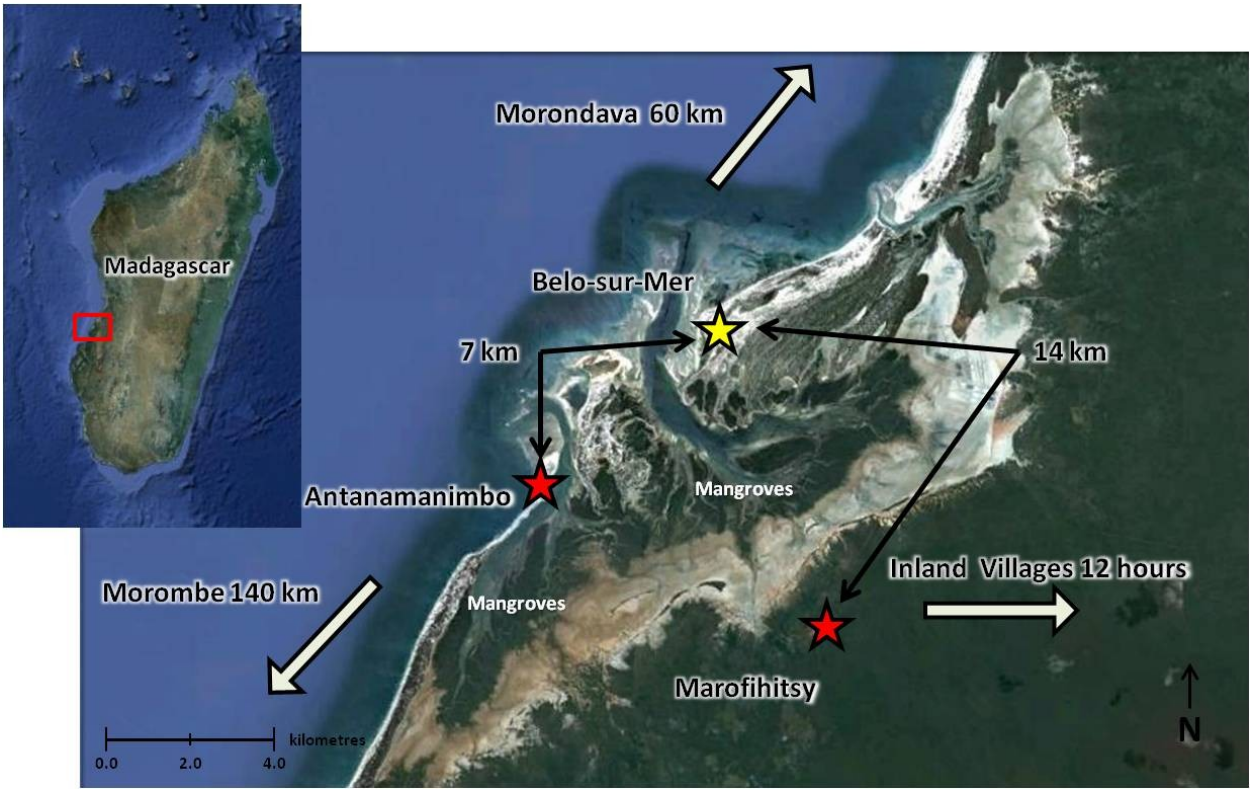

Figure 2: Approximate distances between local markets in Antanamanimbo and Marofihitsy, the middle-distance market in Belo-sur-Mer and long-distance markets in Morondava, Morombe and various inland communities (adapted from Google Earth, 2012)

4.1.2 Market Integration in Antanamanimbo

Economic activity in Antanamanimbo occurs with integration into a large network of markets by means of multiple avenues and channels for exchange. Crabs and fish caught in Antanamanimbo are sold to local or visiting sous-collectors who will then transport the catches to markets elsewhere on the coast. These collectors will sell products from Antanamanimbo in markets as far away as Morondava, sixty

kilometres to the north. It is speculated that crabs sold by sous-collectors may even be found in markets in Antananarivo, hundreds of kilometres away.

The level of market integration that is present in Antanamanimbo is the result of the combined factors of geographic location, transportation technology, and cultural practices of its population. Located on the coast, Antanamanimbo has access to an efficient and inexpensive marine transportation network. *Boutry*s, the large sailing vessels manufactured in Belo-sur-Mer, are used to transport reasonably large shipments of goods up and down the coast. Sous-collectors working for larger companies that process and market marine products, on a national or international scale, have motorized pirogues that they use to visit and purchase catches from fishing communities all along the coast. On a local scale, many of the community members own or have access to *laka*s or *molanga*s that they use to transport their catches and access markets in neighbouring communities.

As nomadic fishers, many of the Vezo have had the opportunity to travel much of the coast and visit much larger centres and markets, such as Morondava. This connection and exposure to a broader community with a greater presence of manufactured and consumer products, along with external cultural influences, create demand for monetary wealth that may be used to participate in this broader market place.

The extent of market integration in Antanamanimbo is focused on the exchange of a limited range of products in order to generate incomes for households in this community (see sections 4.3.5 and 4.5.3), indicating a relatively high degree of specialization in the pursuit of productive activities.

4.1.3 Limited Market Integration in Marofihitsy

Economic activity in Marofihitsy occurs on a scale that has a much greater focus on local exchanges relative to that in Antanamanimbo. In this community the formal monetary exchange system is complemented by an informal barter economy that plays a key role in meeting the needs of the population. In the barter portion of this type of market system, commodities are exchanged directly for other commodities. Rather than rely entirely on money as a symbolic representation of a given commodity's value, a given commodity is also valued on its immediate importance to the parties involved in the exchange and in real terms of whatever is being offered in exchange.

Formal market activity is linked to the local sale of crabs, fish, and molluscs caught in the mangrove, which will be presented in greater detail in sections 4.3.5 and 4.5.3. Households also sell their agricultural products (maize, cassava, vegetables and livestock) to purchase small quantities of goods such as sugar, coffee, and tobacco. Individuals may travel fifteen kilometres to Belo-sur-Mer to access the larger market there or go to other smaller communities in the area (see Figure 2). However, during the study period, this area was suffering from an extended drought, and low crop yields resulted in little surplus available to be sold. One household in the community operates an epi-bar (cafe) which sells coffee and some other goods, while another household runs a small shop. Some individuals work as carpenters constructing or rebuilding houses in the community.

The limited market integration in this community is supplemented by a system of barter and non-monetary exchanges. In one household where the adults work as herders looking after livestock for another member of the community, the herders are paid in food and in livestock, receiving two zebu (priced at 150 000 Ar/zebu – 75 USD$/zebu) for one year of work. This barter system extends to a regional level through the trade of mangrove crabs for rice from communities with surface water available for irrigation. Crabs are purchased or bartered for by one household in Marofihitsy then transported inland by zebu-cart to communities up to 12 hours away. In these inland communities, crabs are then traded for rice at a rate of one crab for two kilograms of rice. Rice is then sold or traded in exchange for more crabs back in Marofihitsy. As rice is the staple food of the Malagasy diet, this system of hybrid economic activity is essential in maintaining the survival of the people of Marofihitsy.

The effects of greater isolation and limited production combine to result in a low flow of monetary capital into the community and low levels of monetary exchange among community members. However, limited access to monetary capital appears to be supplemented in part by the use of the above mentioned system of bartering and the maintenance of a diverse range of productive activities, see section (4.3.5).

4.2 Summary of Human Well-being Comparison

The basic components of human well-being as represented by demographics, education, incomes, and diets in Antanamanimbo and Marofihitsy are summarized in Table 3. This material illustrates key differences between these two communities in literacy, monetary incomes, and daily calorie and protein intake.

Table 3 : Summary comparison of the key components of human well-being in Antanamanimbo and Marofihitsy

	Antanamanimbo	Marofihitsy
Total Population	187	190
Mean Household Size	5.67 ±3.14	5.14 ±2.49
Mean Age	18.16 ±16.67	18.96 ±16.64
Adult Literacy	32.89%	20.73%
Youth Literacy	38.46%	32.69%
Household Mean Annual Income (Ar)	2 078 224 ± 1 394 247	649 824 ± 548 977
Total Calorie Intake (kcal/day)	2327.47 ± 1141.01	2156.67 ± 1153.26
Total Protein Intake (g/day)	120.58 ± 93.92	74.24 ± 44.83

4.3 Components of Human Well-being

This section describes in detail the proxies for human well-being that were found through household surveying and focus groups performed in this case study. These include breakdowns of the demographics and educational attainment of the populations of Antanamanimbo and Marofihitsy, comparisons of major components of diets, food insecurity, incomes, isolation, and other non-dietary components of material well-being.

4.3.1 Demographics

Gender distribution of populations in each community, household sizes, means and modes of ages in each community are detailed in Table 4. The age structure of populations are very similar in each of these communities and demonstrates that they are both heavily weighted towards lower-age classes (see Figure 3). Antanamanimbo has two citizens over 75 years of age, while no households in Marofihitsy had members over the age of 70 at the time of surveying, the oldest person in Antanamanimbo was an 80 year-old woman, ten years older than the two eldest people in Marofihitsy.

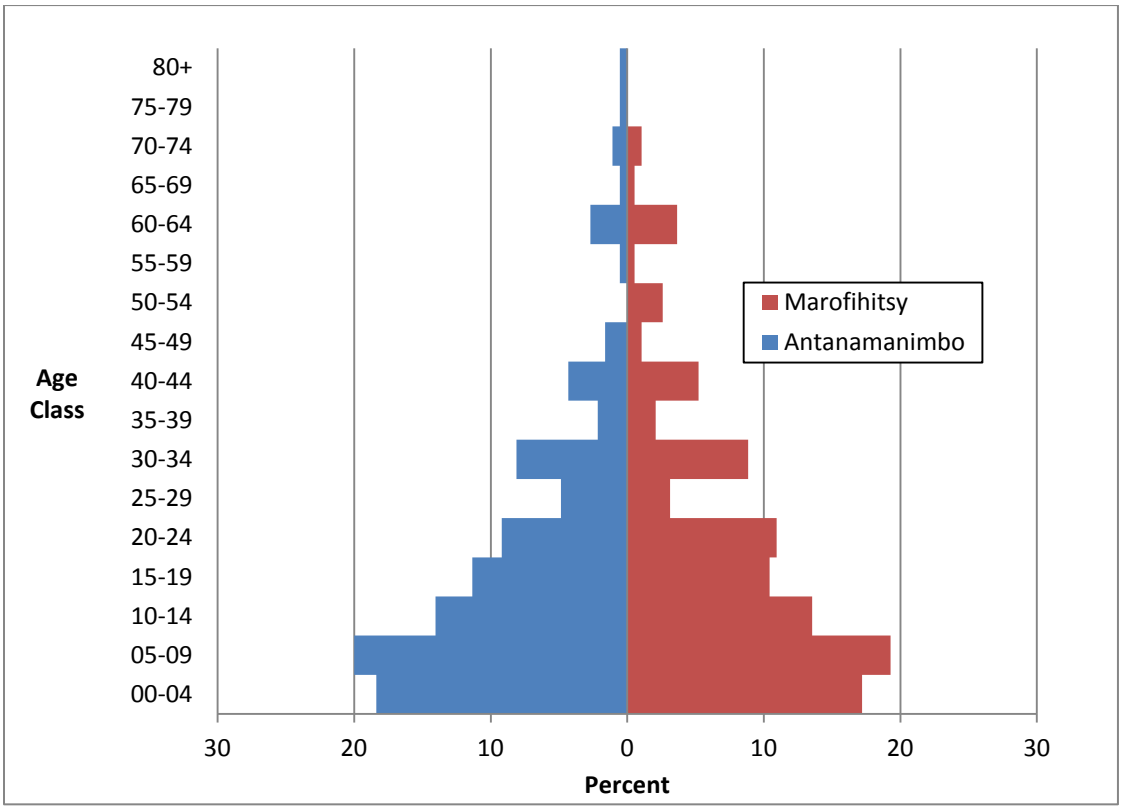

Figure 3: Percentage of population by age class for the communities of Antanamanimbo and Marofihitsy in 2011

Table 4: Population distribution and household size in Antanamanimbo and Marofihitsy

	Antanamanimbo	Marofihitsy
Households	33	37
Total Population	185	192
Mean Household Size	5.67 ±3.14	5.14 ±2.49
Male	53.51%	50.52%
Female	46.49%	49.47%
Mean Age	18.16 ±16.67	18.96 ±16.64
Age Mode	10	30

4.3.2 Educational Attainment

Participation in formal education and levels of adult and youth literacy are presented in Table 5. The youngest community members to have attended school were age four at the time of surveying, yet no one under the age of seven was recorded as literate. The characteristics of being of school age, but not yet literate were used to distinguish between youths and children for the purposes of assessing educational attainment. Adults and youths were differentiated as to whether or not they were over the age of 18 at the time of surveying.

Table 5: Educational Attainment and Literacy in Antanamanimbo and Marofihitsy

	Antanamanimbo	Marofihitsy
Adult (age ≥18)		
Literate	32.89%	20.73%
With Formal Education	35.53%	21.95%
Average Educational Attainment (years in school)	1.39	1.10
Youths (age 7-17)		
Literate	38.46%	32.69%
With Formal Education	63.46%	51.92%
Average Educational Attainment (years in school)	1.40	1.46
Children (age 4-7)		
With Formal Education	57.14%	25.00%
Number of literate households	15	19

4.3.3 Diet

When comparing diets between the two communities significant differences ($p > 0.05$) were not present in individual daily caloric intake. Mean caloric intake was slightly higher in Antanamanimbo than Marofihitsy (see Figure 4: A). However, Marofihitsy demonstrated lower minimum and maximum

caloric intakes than Antanamanimbo, 638.97 kcal/day and 5095.03 kcal/day compared to 1024.49 kcal/day and 5713.41 kcal/day. Significant differences ($p < 0.05$) were found in total individual protein consumption between communities, with total protein consumption being much higher in Antanamanimbo (see Figure 4: D). This difference in diets shows even greater significance ($p < 0.001$) when comparing consumption of animal source protein and calories between communities (see Figure 4: B and E). Mean plant based calorie intake is nearly the same between communities (see Figure 4: C). While daily plant based protein consumption is significantly higher in Marofihitsy ($p = 0.003$) (see Figure 4: F).

At the time of this study the majority of vegetable/carbohydrate contributions to diets consisted of the staple rice, followed by maize and cassava. A small number of households consumed sweet potatoes and occasionally the consumption of fruit and groundnuts were noted. However, fresh fruit and nuts were not noted to be consumed on a regular basis or by the majority of households during the study period and did not constitute a significant portion of diets.

Beans, groundnuts, and coconuts were counted as alternative sources of protein in both communities with consumption being higher in Marofihitsy. However, for both communities the number of households and the total kilograms of these products that were consumed on a weekly basis were much lower than the number of households and the volume of animal products that were consumed. In Marofihitsy, the consumption of beans, groundnuts, and coconuts accounted for less than half that of the protein intake per individual represented by fish and marine products. Although, given the composition of these food products they provided a greater contribution to calories consumed. Of the households in Antanamanimbo, 45 percent indicated that they had consumed beans, groundnuts or coconuts in the week prior to surveying, but the total volume being consumed amounts to only two percent of protein and less than seven percent of kcal derived from fish and marine products. In Marofihitsy most of households purchased these products rather than growing them themselves. The same can be said for all of the households in Antanamanimbo that consumed beans, groundnuts, rice, cassava, and maize. Although none of the respondents in Antanamanimbo indicated that their households harvested coconuts for their own consumption, individuals were observed climbing coconut palms in pursuit of this product.

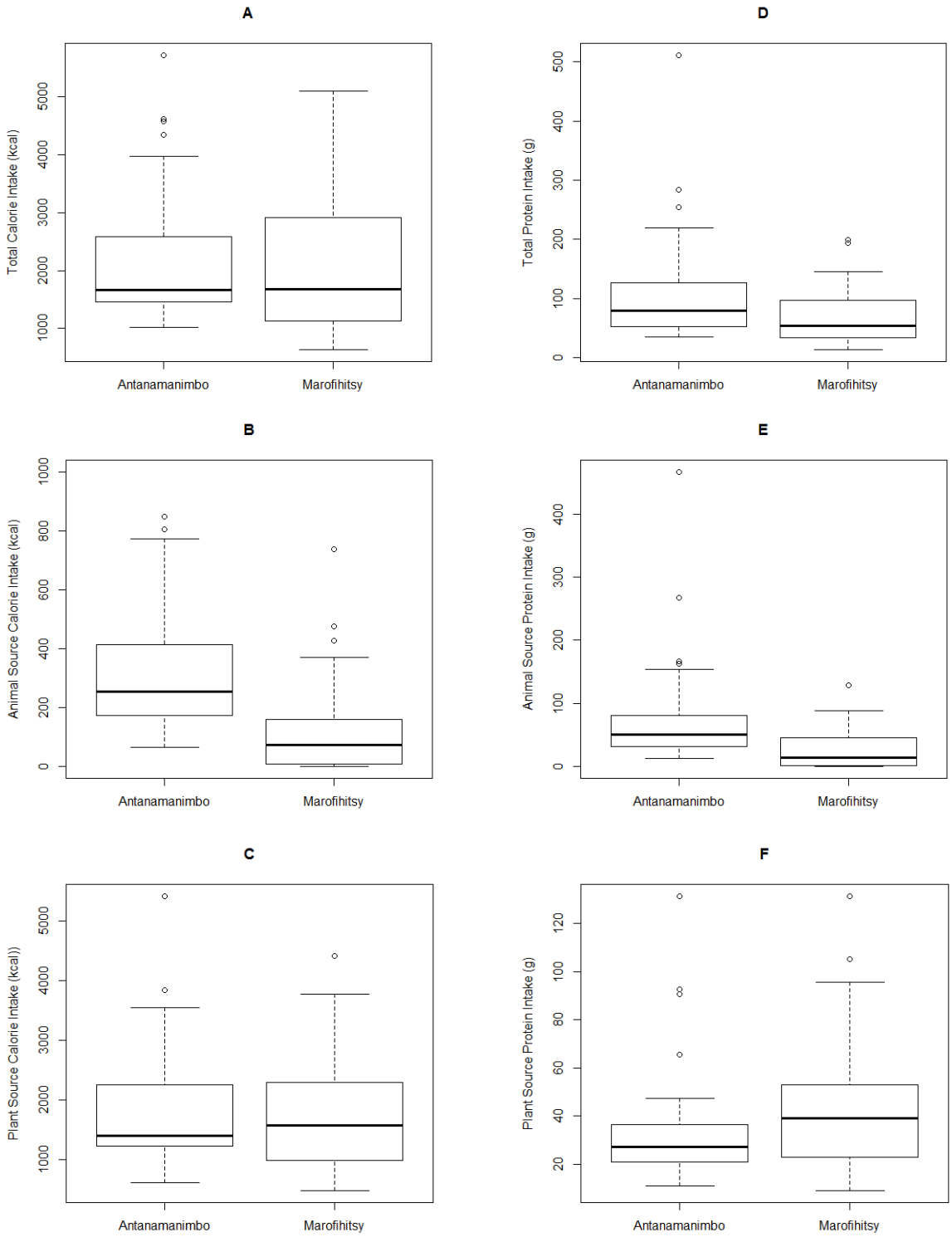

Figure 4 : A - Total calories consumed per person, mean Antanamanimbo (*A*) 2124.03 ±1067.74 kcal/day, Marofihitsy (*M*)1941.47 ±1079.69 kcal/day; B – Animal source calories consumed per person, mean *A* 331.46 ±251.46 kcal/day, *M* 149.53 ±226.33 kcal/day; C – Plant source calories consumed per person, mean *A* 1792.57 ±993.15 kcal/day, *M* 1791.94 ±992.03 kcal/day; D – Total protein consumed per person, mean *A* 97.82 ±60.18 g/day, *M* 66.74 ±40.76 g/day; E – Animal source protein consumed per person, mean *A* 63.19 ±49.94 g/day, *M* 24.21±27.07 g/day; F – Plant source protein consumed per person , mean *A* 34.64 ±25.89 g/day, *M* 42.53±25.42 g/day

4.3.4 Food Insecurity

In both communities the number of households experiencing food insecurity peaks during the summer season (*Asara*) between December and February, (see Figure 5). Fewer households experienced food insecurity during the remainder of the year. Although Antanamanimbo contains a higher total number of households that experienced food insecurity, it contains few households facing a lack of food for much of the year.

In Antanamanimbo, only two households, representing five individuals, responded to say that they faced food shortages for the entire previous year. In Antanamanimbo 26 households responded that they suffered from food insecurity at some point during the past 12 month. This represents 79 percent of the village's households and 72.19 percent of the population.

In Marofihitsy, food insecurity was identified as occurring at least once in the last 12 months for 21 of 37 (56.76 percent) households. These households contain 52.63 percent of the community's population. Of these, five households faced food insecurity for the entire year and there was no month in which less than 32 individuals faced food shortages. When total months of food insecurity faced by individuals are compared, Antanamanimbo had only 347 person-months of food insecurity relative to 513 person-months of food insecurity in Marofihitsy.

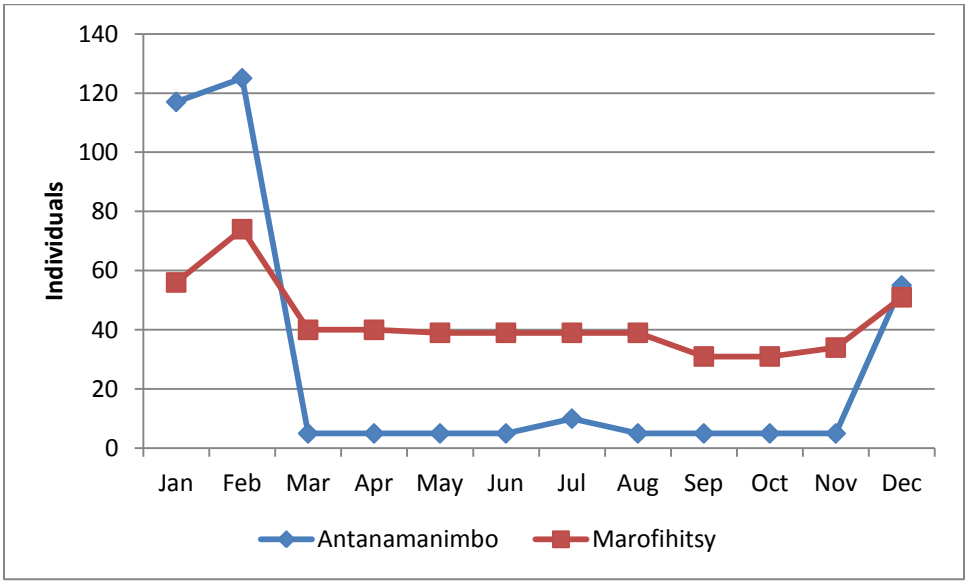

Figure 5 : Total number of individuals represented by households identified as facing food insecurity for part or all of given months over a one year period

4.3.5 Income

Comparing market activity and monetary exchanges occurring in Antanamanimbo and Marofihitsy illustrate many differences between the two communities. The mean annual incomes of households in the communities were significantly different ($p < 0.001$), as shown in Figure 6, with the total annual income for Antanamanimbo (67 967 800 Ariary or 33 983.90 USD$) being much higher than that of Marofihitsy (23 875 500 Ariary or 11 937.75 USD$). The conversion rate for the Malagasy Ariary is approximately Ariary 2000 to USD$ 1 (World Bank, 2013).

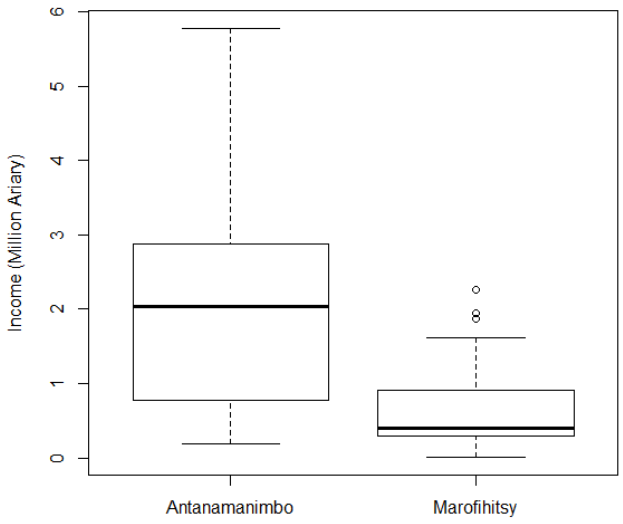

Figure 6 : Household mean annual incomes for Antanamanimbo (2 059 630 ± 1 402 148 Ar) and Marofihitsy (645 283 ± 547 441 Ar)

Perceived productive activities and perceived sources of incomes also differed widely between communities. Household responses to what they identified as primary and secondary occupations by gender and sources of incomes are displayed in Table 6.

Table 6: Breakdown of productive activities in Antanamanimbo and Marofihitsy by perceived time spent on activity and perceived importance of income sources

	Antanamanimbo	Marofihitsy
	Activity (% of Households)	**Activity (% of Households)**
Male Occupation		
Primary	Fisher (85%)	Farmer (59%)
Secondary	Crab Fisher (6%)	Fisher (24%)
Female Occupation		
Primary	Fisher (48%)	Farmer (41%)
Secondary	Domestic Worker (27%)	Fisher (35%)
Perceived Income Sources		
Primary	Sale of Fish (85%)	Sale of Agricultural Products (38%)
Secondary	Sale of Crabs (63%)	Sale of Agricultural Products (22%)

The real distribution of monetary incomes and the respective productive activities from which they are derived are diplayed in Figure 7. The community of Marofihitsy presents a much wider range of income-generating activities than those found through household surveying in Antanamanimbo. In Marofihitsy, incomes were reported as derived from sources that were not identified as present in Antanamanimbo. These included the sale of goods in a local market, selling crops or livestock, food services in the form of dining in a small cafe, or working as a carpenter.

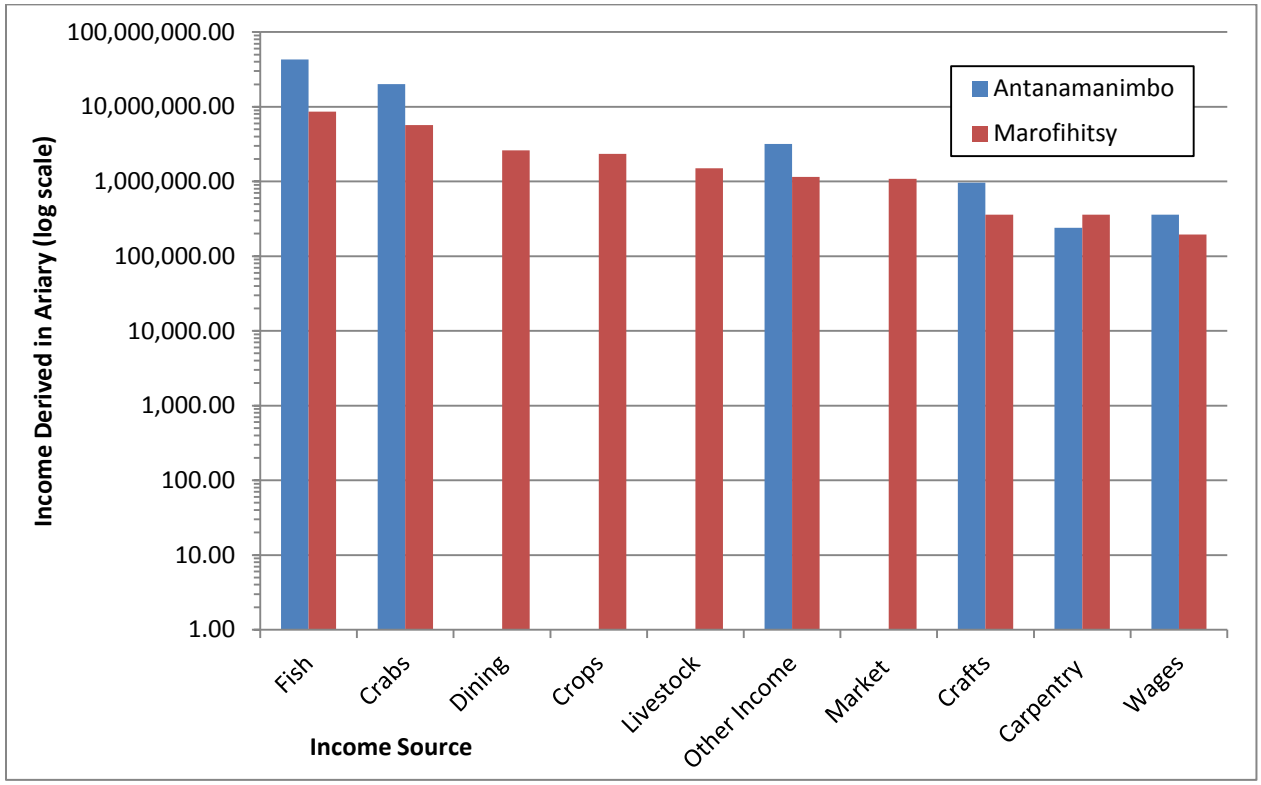

Figure 7 : Total monthly incomes for the communities of Antanamanimbo and Marofihitsy, broken down by the type of income generating activity in Ariary (Ar 2000 = USD$1)

4.3.6 Non-dietary Components of Material Well-being

Energy and Lighting

All households in Antanamanimbo responded that they cook over wood fires rather than using charcoal or any other improved fuel source. Responses were the same for Marofihitsy with the exception of one household which indicated they use charcoal as their primary fuel source for cooking.

Oil lamps were the primary source of lighting in both communities. In Marofihitsy, two households indicated that they own electric torches that they use as secondary sources of lighting. Electric torches represented the primary sources of lighting for four households and the secondary source of lighting for one household in Antanamanimbo for a total of 15 percent of households. One household in Antanamanimbo ran a generator to provide the primary source of lighting in their home, while another used an electric lamp charged by a small solar cell as their secondary source of lighting. However, there were five households in Antanamanimbo (15 percent) that possessed no sources for lighting other than wood fires. In Marofihitsy only three households (8 percent) were limited to the use of wood fires for lighting after dark.

Three households in Antanamanimbo owned generators at the time of the survey. There were no generators owned by households in Marofihitsy.

Building Style

Standard styles of construction differed mainly between the thatch wall design used in Antanamanimbo and the mud wall design used in Marofihitsy. The standard design in Antanamanimbo follows a pattern of wooden pole frames where the walls are woven and roofs are thatched using cut reeds that are imported to the community. Tarpaulins, sails and other materials are occasionally used to supplement or substitute the reed thatch for roofing. The majority of houses in Marofihitsy are constructed using pole frame walls covered with mud. Roofs are thatched using cut reeds, baobab bark and tarpaulins, or combinations of all three. A small number of buildings including the school and houses owned by people who run shops in the community are of more rigid construction, using planks, concrete floors and tin roofs. The cost of building a thatch walled house in Antanamanimbo was calculated to range from 30 000-100 000 Ariary, while construction of a standard mud walled house in Marofihitsy was reported to fall between 30 000-60 000 Ariary.

Thatched roofs were the norm in both communities mostly using reeds or, in the case of some houses in Marofihitsy, baobab bark. In Marofihitsy, six households (16 percent) lived in buildings using 'improved'

materials such as wood planks or sheet metal, four (11 percent) were roofed with sheet metal. Woven mats were used for flooring in 51 percent of homes (19 households) in Marofihitsy, while 30 percent of homes (11 households) had dirt floors. Wooden plank flooring was present in 16 percent of homes (6 households) and one home had a concrete foundation and flooring in Marofihitsy. In Antanamanimbo, all roofs and walls were constructed using the pole and thatch design, with the exception of three households (9 percent) living in tents and two households (6 percent) without any shelter yet constructed. One household in Antanamanimbo was constructed with wooden plank flooring, while all other permanent homes (85 percent) and one of the tents had woven mats over sand for flooring.

Hygiene

Access to soap was higher in Antanamanimbo where fourteen households (42 percent) reported soap being used for personal hygiene over only six households (16 percent) in Marofihitsy. Open defecation is performed in both communities rather than the use of any improved sanitation systems. To mitigate the hygiene impacts of this practice, Antanamanimbo benefits from having tidal action carry away and dilute some of the waste left by open defecation. In Marofihitsy the presence of domestic pigs results in the removal and conversion of human faeces into animal waste. The presence of flies around homes was noted to be only slightly higher in Antanamanimbo than in Marofihitsy.

Other Assets

The possession of a range of high value assets representative of monetary wealth and material well-being indicated further differences between the two communities. The breakdown of the presence of the assets in each community is presented in Table 7.

Table 7 : Count of high value assets in Antanamanimbo and Marofihitsy

	Antanamanimbo	Marofihitsy
Asset	**Number**	**Number**
Generator	3	0
Cell Phone	7	1
Radio	15	11
Television	4	0
Molanga	20	1
Sailing Pirogue	8	0
Shark Net	4	0
Oxcart	0	15
Plow	0	1

4.4 Mangrove Visitation

Patterns of mangrove visitation (for fishing, travel or any other purpose) differ widely between Antanamanimbo and Marofihitsy Figure 8.

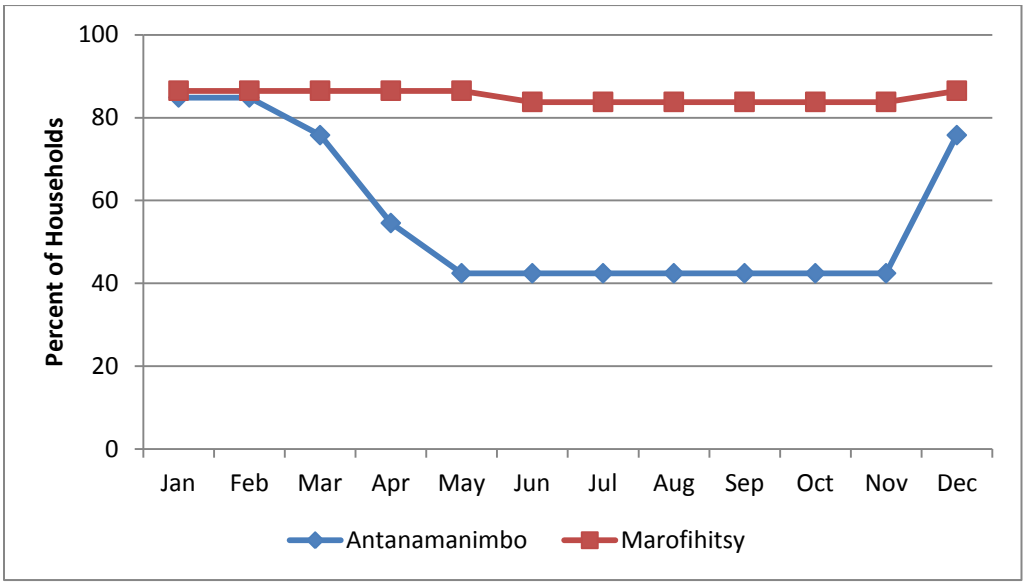

Figure 8 : Percent of households with at least one member visiting the mangrove complex each month

In Marofihitsy, mangrove-household interaction is relatively consistent year round, with the number of households that visit the mangrove each month varying between 31 and 32. However, the number of visits per month varies by household, as demonstrated by the fact that only 21 households had visited the mangrove in the week prior to surveying. Focus group participants stated that "most people only go during the lower tide, maybe half the month". It was also stated that household members have two paths which they may follow: "one to guard the farm and they go less to catch things in the mangrove" and the "other path many go to catch and sell from the mangrove". However during May, June and July more time is spent farming and less is spent going to the mangrove.

Antanamanimbo's levels of mangrove interaction are linked to the seasons and general weather patterns. Mangrove visitation peaks during the summer months of *Asara* when high winds and storms make fishing offshore dangerous. Only 14 households indicated that they fished in the mangrove for the entire year prior to surveying, while 11 fished in the mangrove for the four months of *Asara* and three fished there for only three months of the previous year. All 14 of the households that fish in the mangrove year round responded as having visited the mangrove in the week before being surveyed.

For individuals from Marofihitsy to reach the edge of the mangrove forest, they must travel on foot for approximately half an hour. None of the households in this community indicated that they owned boats in which they could travel inside of the mangrove. However, one *molanga* was observed tied up in the mangrove at the end of the path leading from Marofihitsy. Total time allotted to fishing in the mangrove would be determined by the time available between tides.

Fishers from Antanamanimbo use boats (*laka* or *molanga*) to cross the lagoon separating their community from the mangrove and to travel up channels within the mangrove, they also travel on foot from the south end of the village around the lagoon and within densely forested areas of the mangrove. Survey respondents indicated that travel times to reach fishing sites in the mangrove could range between fifteen minutes to two hours.

4.5 Mangrove Provisioning Services

The provisioning services derived from the Belo-sur-Mer mangrove are presented in this section through the contributions made by the mangrove to various fisheries, the importance of mangroves in local diets, incomes, and the provision of shelter and fuel.

4.5.1 Fisheries

In both Antanamanimbo and Marofihitsy the Belo-sur-Mer mangrove complex is essential in supporting the fisheries utilized by these communities. Targeted species include the mud crab (*Scylla serrata*), various species of fish, shrimp, whelks (*sakody*) and hermit crabs (*marotondro*). Table 8 provides a breakdown of the catches made in the mangrove during the week prior to surveying.

Table 8 : Recorded catches from the mangrove for the week prior to surveying in Antanamanimbo and Marofihitsy

	Antanamanimbo			Marofihitsy		
Type	**% of HH**	**Total kg**	**Mean kg/HH**	**% of HH**	**Total kg**	**Mean kg/HH**
Crab	42.42	729.25	52.09 ± 51.20	45.95	287.45	19.16 ± 25.47
Fish						
- Small	15.15	349.50	69.90 ± 24.57	0.00	0.00	NA
-Medium	9.09	219.00	73.00 ± 90.57	35.14	121.00	9.38 ± 8.90
-Large	3.03	210.00	210.00 ± 0.00	0.00	0.00	NA
Shrimp	6.06	2.00	1.00 ± 0.00	2.70	3.00	3.00 ± 0.00
Sakody	0	0.00	NA	10.81	8.25	2.06 ± 2.34
Marotondro	0	0.00	NA	10.81	9.60	2.40 ± 2.44

Crab

The most notable fishery for a single species that can be directly linked to the mangrove is that for the mud crab *Scylla serrata*. Crabs play a large role in the diets for both communities as well as being essential features in local economic exchanges. Mud crabs are fished year round by households from both communities, but catches and the number of fishers increase during the austral summer months of *Asara* when young crabs enter the mangrove after maturing in the ocean. It was mentioned by focus group participants in Antanamanimbo that more fishers from outside the community enter the mangrove at this time in order to catch crabs.

In Antanamanimbo 82.82 percent of households (27) indicated that they fish for mud crabs in the mangrove on either a seasonal or year-round basis. In this community 14 households had caught crabs in the week before surveying. Of the 37 households in Marofihitsy, 30 households (81.08 percent) fish for mud crabs; half of these (15 households) had caught mud crabs in the previous week.

Key informant interviews indicated that crabs were caught using five different methods in this area. One of the most popular methods is by using a *kipao* or *lombo*. The *kipao* resembles a tennis racket with very loose strings made with fishing net and a frame. It is popular as it allows the user to potentially catch multiple crabs in one scoop. The *lombo* is a larger version of the *kipao*. The second most common method uses the *fanongitsy*, a long pole with a hooked end that can be used to catch one crab at a time. The final two methods include the use of a scuba mask in order to catch the crabs by hand, or by using a paddle. Many of these methods may be employed when tides are high enough to allow *molangas* or *lakas* to enter the mangrove and the fishers to catch the crabs while they are submerged; but the crabs may also be caught by finding their burrows when they are exposed at low tide.

After capture, the crabs' claws are tied using palm fibres. They are then lightly coated in mud and stored live in gunny sacks for up to two weeks. During this time they may be used for household consumption, sold locally or transferred to other markets.

Analysis of 182 live crabs caught in the Belo-sur-Mer mangrove complex, for consumption or sale, yielded the following biophysical data on catches made at the time of this study. Males represented 52.75 percent of those caught with a mean weight of 0.48 ± 0.26 kg/crab and mean carapace width of 11.61 ± 1.89 cm. Females amounted to 47.25 percent of catches with a mean weight of 0.43 ± 0.18

kg/crab and mean carapace width of 11.44 ± 1.50 cm. Mean weight and carapace width were not significantly different between sexes ($p > 0.05$).

Laws governing the mud crab fishery were set by the fishermen in this industry. By these rules crabs that are harvested must have a carapace width greater than 10 cm. The rules state that fishers are not allowed to harvest crabs with eggs. The crabs cannot be caught when they have soft shells as a result of undergoing a molt, because this is when they are able to reproduce and are likely to have eggs. There are no laws requiring fishers to differentiate between male and female crabs and as a result many that contain eggs are harvested.

Finfish

The relationship between the mangrove system and catches of finfish, particularly in Antanamanimbo, is much more complex those of species harvested in the mangrove. This is predominantly a result of the fact that most species and populations of fish do not remain in the mangrove for their entire life cycles, or even for entire tidal cycles (Hogarth, 2007). Yet, many species act as conveyors of biomass, transporting energy and material from the factory of high primary productivity that is the mangrove out into surrounding marine ecosystems and food webs (Hogarth, 2007).

In assessing finfish catches made in Antanamanimbo, survey participants indicated that a total of 770 kg of fish were caught in the mangrove in the preceding week. This value represents 32 percent of the preceding week's finfish landings recorded during surveying. Analysis of annual catch data from a geo-referenced data set collected in Belo-sur-Mer from a group of fishers with similar practices to Antanamanimbo show that annual finfish landings from fishing sites in the mangrove and associated estuary would yield approximately 10 percent of total finfish landings for fishers from this neighbouring community.

Furthermore, catches of fish in Antanamanimbo could be broken down into three classifications. The first, *provandy*, consists of fish that are too small to be preserved by salting and receive a low price when sold. The second, *fia frire*, refers to medium sized or damaged fish that are large enough to salt well, but not large enough or of the level of quality that would allow them to fetch the highest prices. Finally, *fia vary*, are large fish that salt well and can be sold at a premium. Fishers in Marofihitsy did not make this distinction between quality classes of fish and corresponding prices.

As Marofihitsy's community members only fish in the mangrove, the full weekly landing of 172 kg that was made by this community is recognized as coming from the mangrove. The classification of these

fish as “medium” in Table 8 is a result of the general lack of differentiation of fish into different size and value categories by fishers in Marofihitsy. This classification fits with the general similarity between treatment of fish for sale in Marofihitsy by salting and drying and comparability between the standard prices received for fish in Marofihitsy of 1000 Ar/kg and Antanamanimbo’s average price 1075 Ar/kg for medium fish that may be dried and salted.

Survey respondents, focus group participants, and key informants from Marofihitsy identified hook and line as the only method used by fishers from this community when catching finfish in the mangrove. Belonging to a fishing community, Antanamanimbo’s residents identified a wider range of methods used when fishing in the mangrove. These include hook and line fishing, but also include the use of a range of nets to harvest fish from the mangrove channels.

Sakody and Marotondro

During a focus group in Antanamanimbo the participants indicated that members of their community do harvest *sakody* and *marotondro* (whelks (*Terebralia palustris*) and hermit crabs (*Coenobita violascans*)) from the mangrove. Middens containing shells from these creatures also show that they are consumed in the community. However, as they were not mentioned during surveying, and based on conversations with key informants, *sakody* and *marotondro* are viewed as less desirable foods and are rarely harvested by members of Antanamanimbo outside of *Asara* and the months of high food insecurity.

Many households in Marofihitsy harvest and consume both *sakody* and *marotondro*. Six households harvested *sakody* and eight harvested *marotondro* in the week prior to surveying. Average catches were 2.06 kg/HH/week and 2.40 kg/HH/week, respectively. Consumption of these catches spreads their influence to a wider range of households, with 11 consuming *sakody* and 14 consuming *marotondro* in the week before being surveyed. Those who consumed, but did not catch these species during the study period purchased them from the households who harvested them at a rate of 2500 Ar/kg. For the entire community the combined consumption of *sakody* and *marotondro* accounted for 1.14 percent of total caloric intake, 12.16 percent of protein intake and 33.51 percent of animal source protein intake.

Shrimp

The role of the mangrove in supporting the artisanal shrimp fishery in these two communities appeared to be under represented by the household surveying portion of this study. Eight households in Antanamanimbo (three in the week prior to being surveyed) and one household in Marofihitsy responded that they catch shrimp in the mangrove. However, during the focus groups it was mentioned

that a large number of people catch shrimp from October to December. The Antanamanimbo focus group stated that the shrimp can be sold for 2800 Ar/kg dried and that the price increases to 3000 Ar/kg during *Asara*. From the survey material good catches could amount to up to 70 kg a day, while normal catches stood at an average value of 18.67 kg/day. Although some of this catch may be accounted for in the annual income received from the sale of fish, due to seasonal shifts in fishing activities, the total contribution of mangroves to catches in the form of shrimp cannot be accounted for in full by this study.

Total Annual Landings

Landings made by households from Marofihitsy were indicated to remain relatively consistent throughout the year. For households from Antanamanimbo seasonal variability in the number of households visiting the mangrove corresponded with respondents indicating that landings made from the mangrove increase with the seasonal shift in fishing patterns.

The proportion of Antanamanimbo's annual non-crab landings from the mangrove was calculated using an extrapolation from the weekly landings reported during household surveying combined with the seasonal contributions to reported annual household incomes from the sale of non-crab marine products.

Estimated annual landings of all species caught in the mangrove amount to a total of 56 456 kg harvested by Antanamanimbo and 22 962 kg harvested by Marofihitsy. The distribution of these catches on a household level is displayed in Figure 9, which shows the mean household annual landings broken down into the categories of mud crabs and other species (dominated by finfish). In both categories the annual landings of species from the mangrove that were made by fishers from Antanamanimbo are significantly higher than those made by Marofihitsy (for crabs $p = 0.001$ and for other species $p = 0.003$).

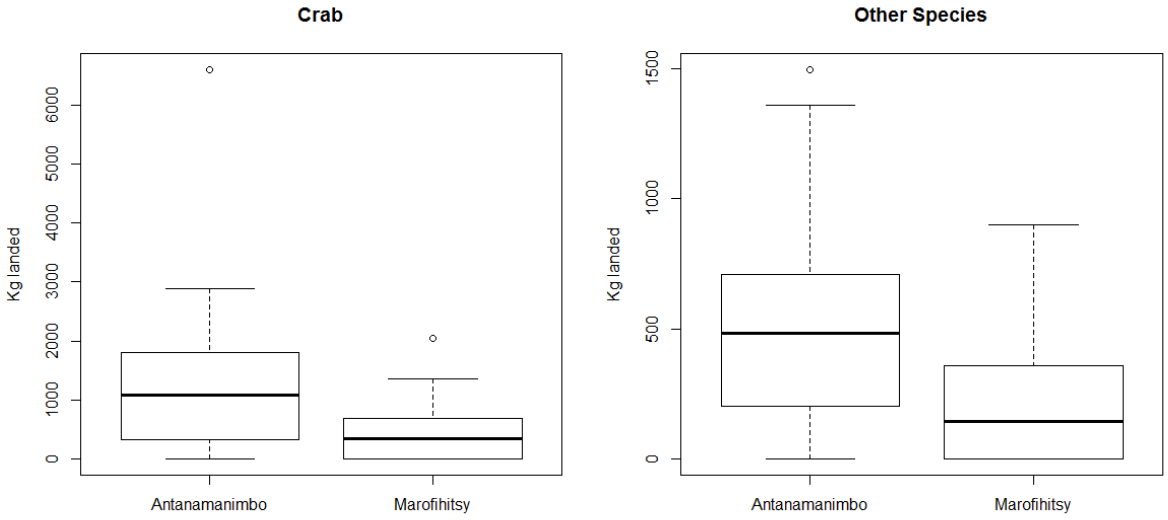

Figure 9 : Annual landings per household from the mangrove by Antanamanimbo and Marofihitsy. Household mean annual landings by Antanamanimbo were 1 216.53 ± 1 216.53 kg for mud crab and 4 94.25 ± 4 07.63 kg for other species. Household mean annual landings by Marofihitsy were 388.37 ± 417.56 kg for mud crab and 232.22 ± 289.18 kg for other species.

4.5.2 Mangrove Contribution to Diets

The mangrove-derived daily calories and protein consumed by household members in Antanamanimbo and Marofihitsy are outlined in Table 9. There is not a significant difference between the numbers of calories derived from the mangrove in each community. The difference between individual consumption of protein derived from the mangrove becomes significant when considered on a 90 percent confidence interval (p = 0.097), with higher consumption occurring in Antanamanimbo. Particular attention should be given to the fact that in Marofihitsy nearly 100 percent of animal-source protein in diets is derived from mangrove sources.

Table 9 : Contribution of mangroves to daily caloric and protein intake in Antanamanimbo and Marofihitsy

	Antanamanimbo	**Marofihitsy**
Calorie Intake from Mangrove(kcal/day)	151.86 ± 215.10	149.52 ± 226.33
Proportion of total calories	7.15%	7.70%
Protein Intake from Mangrove (g/day)	30.43 ± 43.40	24.20 ± 27.07
Proportion of total protein	31.12%	36.25%
Proportion of animal-based protein	48.16%	**99.95%**

4.5.3 Mangrove Contribution to Incomes

The relative contributions of catches from the mangrove to incomes in both communities can be estimated through further investigation of the breakdown of total annual sources of monetary income for both communities (see Figure 10).

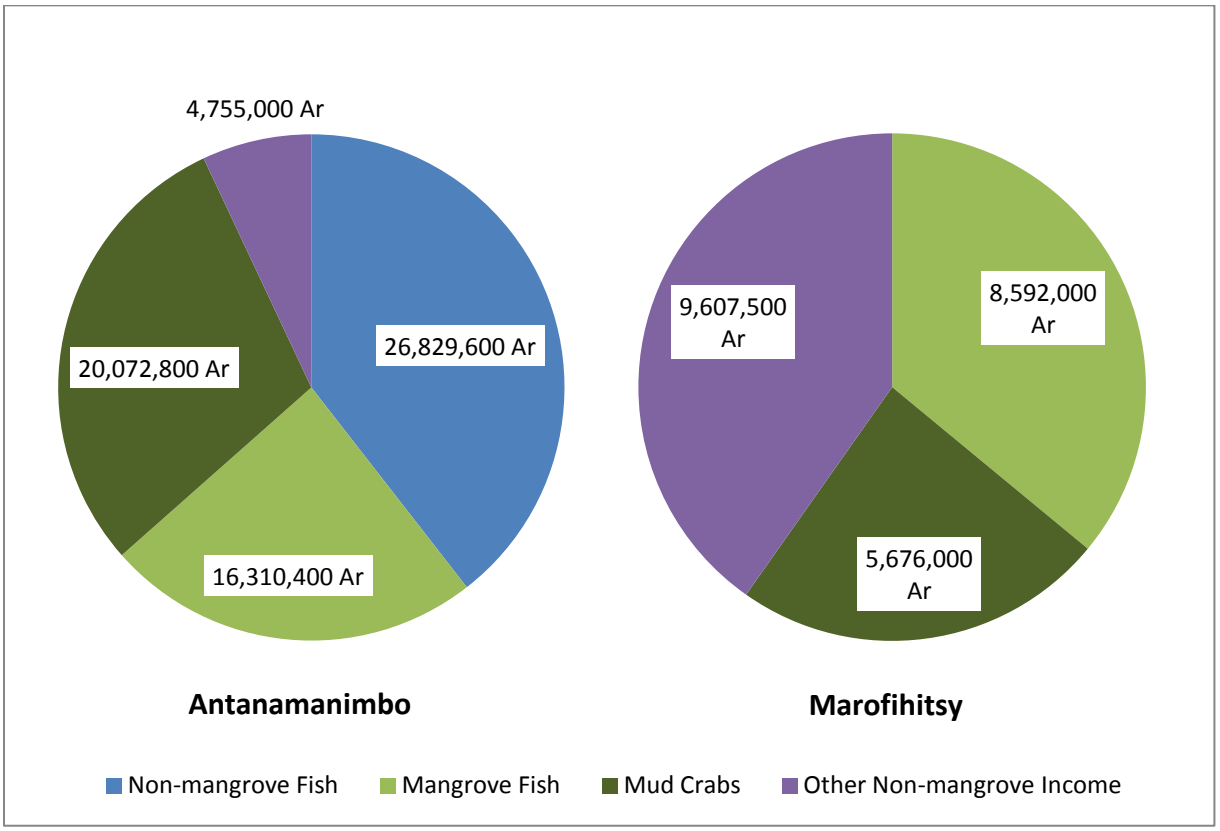

Figure 10 : Total annual incomes for the communities of Antanamanimbo and Marofihitsy, broken down by the type of income generating activity in Ariary (2000 Ar = USD $1). Income sources that are derived from the mangrove include mud crabs and mangrove fish.

The sale of crabs is most easily connected to the mangroves as they are almost exclusively caught in the mangrove by either community. In Antanamanimbo the sale of crabs accounted for 29.53 percent of total annual community incomes for a total of 20 072 800 Ariary (USD$ 10 036.40). Based on extrapolation from the proportion of weekly catches coming from the mangrove, the sale of fish that could be clearly identified as caught in the mangrove contributed 16 510 400 Ariary to total annual incomes (24.00 percent). When combined the sale of products definitely caught in the mangrove account for a total of 53.53 percent of annual incomes, 36 383 200 Ariary (USD$ 18 191.60).

In Marofihitsy, the proportion of total monetary incomes derived from the sale of crabs is 23.77 percent of total annual income for the community (5 676 000 Ariary). As households from Marofihitsy only fish in the mangrove, all incomes from the sale of fish, including *sakody* and *marotondro*, a total of 8 592 000 Ariary (35.99 percent of total community income), can be counted as derived from the mangrove. Combined, the sale of fish and mud crabs have a monetary value of 14 268 000 Ar/year (USD$ 7134.00) and account for well over half (59.76 percent) of all monetary incomes in Marofihitsy.

In Antanamanimbo, 10.70 percent of the population (in five households) were identified as depending on annual household monetary incomes that are only derived from mangrove sources, in this case the sale of mud crabs. In Marofihitsy the limiting of fishing effort to sites only in the mangrove allowed a total of 12 households, representing 41.05 percent of the population, to be identified as having incomes derived solely from mangrove resources.

Market Prices

The prices received for the mangrove products harvested by these two communities vary based on the market in which they are sold (see Table 10). The lowest prices that sellers received are found when they sell goods within their own community for local consumption or when they sell goods to sous-collectors that are either locally based or visiting the community. Higher prices are received in Belo-sur-Mer as a result of the presence of tourist customers, a larger market, and a population that is less dependent on fishery derived incomes. The highest prices received by sellers can be found in more distant markets, such as those in the city of Morondava for the Antanamanimbo sellers or inland villages where rice is farmed for sellers from Marofihitsy. Crabs sold to hotels and restaurants operating in Belo-sur-Mer's small tourism industry fetch a price of 1000 Ar/kg. Fresh fish can be sold for between 1000-2000 Ar/kg, depending on their size and the restaurant in question. The more expensive tourist restaurants then sell the crab and fish for 8000-20 000 Ar/plate. The other restaurants sell them for 3000 or 6000 Ar/plate. Prices received for crabs in Morondava depend on where they are sold. Larger seafood companies will pay a standard rate per kilogram, while sellers in the city's market will offer more by paying fishers 50 percent of the standard rate up front and a follow-up payment at the end of the day, with the size of the follow up payment dependent on the price that sellers received for the crabs over the course of the day.

Table 10 : Standard prices received in various markets for products from mangrove fisheries when sold by fishers from Antanamanimbo and Marofihitsy

Product	Antanamanimbo	Marofihitsy
Crab		
Local	500 Ar/kg	395 Ar/kg
Belo-sur-Mer	1000 Ar/kg	1000 Ar/kg
Morondava	~1000 Ar/kg	
Inland		500-1000 Ar/kg or 2kg rice/crab
Shrimp		
Local	1775 Ar/kg	1000 Ar/kg
Morondava	2800-3000 Ar/kg	
Fish		
Local	1000 Ar/kg	1000 Ar/kg
Belo-sur-Mer	1000-2000 Ar/kg	1000-2000 Ar/kg
Morondava		
High quality	3000 Ar/kg	
Middle quality	1000-1200 Ar/kg	
Lowest quality	600 Ar/kg	
Sakody and Marotondro	N/A	2500 Ar/kg

The trade of crabs between Marofihitsy and the inland villages occurs once a month. The amount crabs taken per trip was stated to amount to about 80 *toko*, approximately 100 kg or 222 crabs. If all of these crabs were bartered for rice, at the rate of one crab for two kilos of rice, the return would be 444 kg of rice with a market value in Marofihitsy of 302 040 Ariary.

4.5.4 Shelter

Antanamanimbo has a great dependence on the nearby mangroves to provide lumber and fuelwood. Despite access to alternative wood and fuel source in markets elsewhere on the coast, the financial, temporal, and labour expenditures required to access these resources are high and limit their use. The mangrove provides a readily available supply of wood products that can be easily accessed by boat from this community.

The regulating service of storm protection provided by the Belo-sur-Mer mangrove forest is also partially illustrated by the data in Table 11. Antanamanimbo was completely unsheltered by the storm as it followed a track from west to east at the time of landfall. Marofihitsy had both the mangrove and a belt of dry deciduous forest in the path of cyclone. Respondents did not identify damage caused by storm

surge. However, rain and high winds resulted in the damage and destruction of a higher percentage of homes in Marofihitsy than in Antanamanimbo.

Table 11 : Homes damaged or destroyed during 2009 cyclone and the cost to rebuild

	Antanamanimbo		Marofihitsy	
	Number	**% of Total**	**Number**	**% of Total**
Homes Damaged	6	18.18	7	18.92
Homes Destroyed	20	60.61	24	64.86
Cost to Rebuild	30 000 – 100 000 Ar (thatch walled)		30 000-60 000 Ar (mud walled)	

In Antanamanimbo, all of the homes that were destroyed by the 2009 cyclone Fanele were rebuilt with wood harvested from the mangrove (see Table 11). The construction used to build homes in Antanamanimbo utilises poles cut from *Ceriops tagal* (TANGAMBAVY), *Rhizophora mucronata* (TANGANDAHY) and *Bruguiera gymnorrhiza* (TANGAMPOLY) for frames and supports. These poles are also used to build fences around some homes or family compounds, as well as in the construction of drying racks for fish.

Although the data collected is not indicative of a monetary value for damage averted by the presence of mangroves, the value of 30 000 – 100 000 Ariary is partially indicative of the replacement cost of storm damage that is supplied by resources from the mangrove. Although no payments are made for wood from the mangrove in Antanamanimbo, market prices for lumber in nearby Belo-sur-Mer were 1500 Ar/plank and 700-900 Ar/pole. The price of purchased wood effectively doubled the cost of constructing a home in Belo-sur-Mer relative to Antanamanimbo. Additionally, the price of thatch was stated to be 700 Ar/bundle with houses requiring 20-90 bundles depending on the size of house and whether walls were made of thatch or another material. The time required to build a home varied from 1-2 weeks depending on whether construction was the sole activity pursued or if the builders had other demands on their time.

4.5.5 Fuelwood

Cooking in Antanamanimbo is performed over wood fires. For the majority of households these fires are fueled using dead wood collected from trees in the mangrove that were killed during cyclone Fanele, which occurred in 2009. Wood is collected by household members during visits to the mangrove to

catch fish or crabs. The quantity of wood collected is limited by the size of the fisher's boat but is usually sufficient to meet the household's needs for a couple of days. New arrivals to the village, who are building houses at the southern end of the community are able to access a small area of dry forest and will collect fuel wood from this area if they are not visiting the mangrove to fish. Survey respondents and focus group members did not indicate that there is a market for fuelwood in their community, either formal or informal.

In contrast, the residents of Marofihitsy do not collect any fuelwood or lumber from the mangrove. Given the distance that must be travelled on foot or by zebu cart to the mangrove and the ready availability of wood in the dry forest surrounding the community, collection of wood from the mangroves is not an attractive option.

4.5.6 Changes in Area of Mangrove Forest

When asked whether the area of the mangrove forest had increased, decreased or stayed the same during recent memory focus group participants and key informants in both communities indicated that the area of forest had generally increased. The death of many trees in the mangrove was noted to have occurred as a result of the cyclone in 2009, but respondents indicated that this did not negatively affect the overall area of the forest and they were not particularly concerned over any long-term impacts from the cyclone damage. The construction of an 'eco-lodge', built using locally sourced materials, in Belo-sur-Mer was identified as major consumer of lumber from the mangrove near Antanamanimbo.

4.6 Cultural Services and Intrinsic Values

Both Antanamanimbo and Marofihitsy derive a number of cultural services from the mangrove forest and its associated natural systems. These cultural services can be divided into the categories of religious services, intrinsic values, and cultural identity.

4.6.1 Spiritual Role

Traditional religion in Madagascar typically revolves around the practice of ancestor worship. In many areas there are complex rituals that have been established surrounding the veneration and care for

deceased relatives. In some cases these rituals are performed for decades or generations following the passing of an individual. These rituals may be complemented by less formal practices regarding spirits' occupation of or connection to certain sites and the establishment of local taboos (*fady*) relating to rules established by the spirits of ancestors.

The sites occupied by spirits can be subject to a range of different rules governing their use and interaction between the living and spirits. These may range from complete prohibition on anyone visiting a particular site or visits only being allowed on the occasion of ceremonies pertaining to the spirits there. Other sites may only have prohibitions on particular activities, such as fishing, hunting, visitation by certain individuals and defecation or other "dirty" activities. A *fady* may pertain to rules established by individuals before their deaths, through communication with the spirits of ancestors, as a result of an occurrence in a particular location or through community consensus on establishing a rule to govern the site. These *fady* may only be active for certain individuals, such as the descendants of the deceased, or may apply to everyone.

In the Belo-sur-Mer mangrove complex there are a number of locations which are believed to be inhabited by various spirits. Some are only recognized by individual families, while others are recognized by entire neighbouring communities. Notably, there are fishing sites where visitors must bring a gift to the local spirit or spirits when they visit. In one case a pool inhabited by a spirit has been used as part of a site selected for a temporary marine protected area intended to support mud crab and fish populations. The presence of ancestors spirits in the mangrove is part of a multigenerational connection to this ecosystem that exists not only as the mangrove meets the immediate needs of the living population, but continues to serve this population even after death.

Many households in both Antanamanimbo and Marofihitsy recognize a spiritual component in the establishment of temporary fishing reserves in the mangrove. The reserves were closed in a ceremony that invokes the ancestors' permission for their closure to harvesting and implies the role of these spirits in generating negative consequences for those who would violate the closure. In each community this process meant that for some households these areas of the mangrove gained spiritual and religious importance only following their closure to fishing and the associated involvement of ancestors' spirits.

Introduced religions, such as Christianity, are also used to recognize the spiritual importance of mangroves for these two communities. When individuals where asked during the survey and focus groups "why the mangroves had spiritual importance?" answered that "[they] may not know why the

mangroves are there, but God made them so they must be important". Other households indicated "[they] do not know why the mangroves are there, but they are complex and have been there for a long time so they must be important".

4.6.2 Intrinsic Values

Although the intrinsic values of the mangroves may not be easily quantifiable in monetary terms for these two communities, there are ample examples that intrinsic values do exist for the mangrove and that they are important to both Antanamanimbo and Marofihitsy. The intrinsic value placed on the mangrove ecosystem was exemplified in the given survey responses that stated "a person may not understand how the mangroves were formed or the complexities of their existence, but that these levels of complexity provide an indication the mangrove's importance".

In the survey people were asked "If [they] did not need any resources from the mangrove would [they] still want them to be there?" In Antanamanimbo 100 percent of respondents said "yes" to this question and in Marofihitsy over 70 percent of respondents answered that they wanted the mangrove to continue to exist even if they did not extract any resources from it. There were many reasons given for this response. These included the religious reasons already mentioned in that the mangrove is there for a reason, even if they do not understand why. Individuals also stated that the mangrove should continue to exist for the animals that live there or for other people who may need to use the mangrove and its resources, or for themselves in case they need the resources from the mangrove in the future. Finally there were individuals who answered that they would want the mangrove to continue to exist, even if they couldn't take anything from it, because it "is pretty or good to look at" or that "looking at the mangrove makes [them] happy". In total, ten households in Antanamanimbo indicated that they wanted the mangrove to continue to exist for reasons other than access to physical resources by themselves or others, now or in the future. In Marofihitsy there were only seven households that indicated that they would want the mangroves to continue to exist for purely intrinsic reasons. For those respondents from Marofihitsy who said that they would not care if the mangrove remained, the majority of their responses were that they would not need it if they no longer received food from the mangrove or if they had alternate sources for the resources that they collect there.

4.6.3 Cultural Identity

The richness of an individual's life or even that of a community is closely linked to their identity and their ability to exist and express that identity.

The Vezo people of Antanamanimbo self identify as fishers, that is who they are and what they do. The definition of this cultural group is not strictly based on ancestry, rather to be Vezo is a regional identity for coastal populations choosing to live as fishers (Cripps, 2009). In questioning them about the number of days per week spent fishing they often answer that they are a fisher, that they fish every day as that is who they are and what they do. They may give this answer even when it is obvious that they have not gone fishing every day due to illness, other tasks occupying their time or simply taking a day off. The option and ability to fish is an important part of who they are and how they feel that their lives are fulfilled.

When focus groups were asked if they wanted their children to see the mangrove as important, both communities responded with "yes". In Marofihitsy they said that this was because "the mangrove supports life from long ago. This is heritage from parents to this generation and to the next generation". Antanamanimbo's response was "because it is their school. The children learn to do the same job of harvesting things from the mangrove". This illustrates the role the mangroves play in supporting fishing that is a part the long-term viability of these communities and the careers and cultures of their members.

For fishers in these communities the mangrove plays an essential role supporting this facet of their cultural identity. For those who catch and sell or consume *Scylla serrata* the mangrove is an essential habitat for this species. Without the mangrove there would be no crab fishery in this region. For fin-fish from the near and offshore fisheries, the mangrove makes a large contribution to the biomass caught by fishers. This occurs through species that depend on the mangrove for juvenile or other stages of their lifecycle or other species that transfer biomass generated by primary productivity in the mangrove out into other areas, as well as species that live in the mangrove and estuary during all stages of their lives. Without the contribution of the mangrove to populations of all of these species, fisheries in the Belo-sur-Mer area would be substantially less diverse and productive. Without these fisheries the Vezo population of Antanamanimbo and the fishers of Marofihitsy would not be able to continue to pursue the lifestyles that they currently enjoy and their cultural identity could cease to exist.

5 Relating Mangroves and Human Well-being

The information displayed by this case study provides a unique insight into the differences between Antanamanimbo and Marofihitsy through proxies for human well-being and mangrove resource consumption at the household level. The complex matrix of relationships between market integration, mangrove ES and human well-being requires discussion from a number of perspectives in order to accurately illustrate the reliance of these two communities on the mangrove ecosystem.

5.1 Fisheries

Both communities rely heavily on the wide range of fisheries present in the mangrove, which constitute the primary scene for human-mangrove interaction at the local scale. Examination of mangrove fisheries provides clear avenues for examining differences between these communities in their levels of reliance on the mangrove. The discussion in this section addresses species targeted, fishing methods and the scale of landings made by each community. The role of mangrove fisheries in supporting local diets and incomes will be addressed in later sections.

5.1.1 Targeted Species

Diversity of target species and market price are indicators for the explaining the differences in mindset for fishers from each community and provides a unique insight into their reliance upon mangrove fisheries. If fishing is primarily performed for subsistence purposes then the range of species landed should reflect selection based on their desirability for consumption or their relative ease of capture. Reliance on mangrove fisheries for the generation of incomes should be reflected in the targeting of species for which there are higher market demand and prices.

Size or Value Class

Neither community identified species or size selection of fish as factors that would encourage fishers to make decisions other than to keep all fish that were landed. Although, some fishers from Antanamanimbo acknowledged that they would try to catch larger fish species found in the mangrove or visit specific fishing sites where they believed that they would be more likely to catch larger fish.

The lack of size selection in landings is comparable to opportunistic harvesting of a wide range of species in other subsistence fisheries with household consumption as the primary goal (Labrosse et al., 2006).

However, Antanamanimbo fishers' attempts at targeting larger fish and household decisions to consume lower-value mangrove products may indicate to what extent commercial markets impact patterns of mangrove resource use. Larger fish cure better and receive higher market prices in Antanamanimbo (see Section 4.5.3), while smaller fish do not. Yet, they are very similar when considered in terms of their nutritional value for immediate consumption.

Studies conducted on fisheries in the Torres Strait show that indigenous fishers working in commercial fleets may choose to keep fish for subsistence consumption that are not considered acceptable commercial catch under present regulations (Busilacchi et al., 2013; Williams et al., 2008). For instance, the Maori Humphead Wrasse is not caught in Australian waters of the Torres Strait for commercial purposes, but taken by Indigenous people working on commercial fishing trips and used for personal consumption (AFMA, 2011). It then seems common practice in artisanal fisheries when subsistence fishers target some species for household consumption while commercially desirable species are sold (AFMA, 2011; Clua et al., 2005; Labrosse et al., 2006; Williams et al., 2008).

Diversity

Results from both Antanamanimbo and Marofihitsy identified *Scylla serrata* (mud crabs) as the single species dominating mangrove fisheries. For Antanamanimbo weekly landings of *Scylla serrata* were nearly as large as all other landings from the mangrove. In Marofihitsy this species accounted for landings that were twice the combined mass of all others taken from the mangrove. Although households in both communities regularly consume mud crabs, the sale of this species also plays a large role in household income generation (see Section 4.5.35.2.3) and this economic value may be a driving factor in generating the proportion of catches composed of this one species.

In a study in the Pacific Islands, subsistence fishers were identified as harvesting and consuming a significantly wider range of species than are targeted for commercial exploitation (Labrosse et al., 2006). This diversity of species in subsistence landings suggests a dispersion of fishing effort, greater resilience, and lower levels of stock depletion relative to commercial fisheries that focus on a small number of species (Labrosse et al., 2006).

Marofihitsy identified that *marotondro* and *sakody* were regularly harvested from the mangrove and consumed by households in the community and that over 40 percent of households had consumed at least one of these species in the week prior to being surveyed. In contrast, respondents from Antanamanimbo identified these species as less desirable for consumption and that fishers would not

target these species unless the fishers were particularly hungry or unsuccessful in catching other species. In Marofihitsy it was indicated that these species were bought and sold at a local level. While in Antanamanimbo the only indication that either species would even be harvested was that they would be eaten during the hungry months.

The targeting of less desirable species by fishers from Marofihitsy is indicative of the subsistence role of mangrove resources in this community. Rather than expressing the option to limit harvest and consumption to larger and easier-to-eat species, Marofihitsy fishers are more opportunistic in their targeting of mangrove resources. This is demonstrated in the apparent use of mangrove fisheries to meet the needs of immediate consumption before consideration is placed on other factors that guide the harvesting and use of mangrove resources.

Of all households surveyed in this case study, only 13 percent indicated that they fish for shrimp. However, other research performed in the fishing communities of this area has indicated that this is an important and lucrative seasonal fishery involving the participation of over 80 percent of households (Jones, 2012). The seasonal nature of this fishery may explain the lack of attention that it was given by survey participants when this case study was performed, as the season for catching shrimp had occurred many months in the past and memory of it would not have been fresh in the minds of respondents. However, the high reported price for shrimp (see Section 4.5.3) and the close linkages that exist between shrimp fisheries and mangroves would indicate that this fishery plays an important role in local human mangrove interaction (Primavera, 1998a; Primavera, 1998b; Rönnbäck et al., 2003). Further research into the choices made by shrimp fishers regarding the sale or consumption of their catch could provide key insights into the decision-making processes that govern the distribution of fishing effort between the pursuit of species for sale or immediate consumption.

5.1.2 Scale

In this case study one of the best measures for identifying overall differences in community-mangrove interaction is by comparing the scale of mangrove resource extraction in the form of annual landings. This provides a direct measure of the physical impact that each community has on the mangrove ecosystem and the resources that it provides. As Antanamanimbo's annual landings were calculated to be twice as large as those made by Marofihitsy (see Figure 9 in Section 4.5.1), it is clear that this community extracts a larger amount of biomass from the mangrove. However, differences in mangrove

fishery landings may not demonstrate a relationship that is proportional to the benefits that each community derives from harvesting these resources, as will be discussed in later sections. In addition, although landings from mangrove fisheries are able to provide for a significant portion of livelihoods in both communities, declines in the number and size of catches have been reported in this region (Jones, 2012). This suggests that the scale of total landings from the mangrove may be at a threshold where further increases may threaten the future viability of important target species and the continued stability of the mangrove ecosystem.

Antanamanimbo and Marofihitsy had significantly different numbers of households participating in mangrove fisheries at the time of surveying, with more households from Marofihitsy fishing in the mangrove. However, Antanamanimbo's smaller number of households had mean landings of crabs that were more than twice those of Marofihitsy. Additionally, for fish with the same market price the mean household landings were over seven times larger in Antanamanimbo at the time of surveying (see Table 8 in Section 4.5.1).

The proportion of Antanamanimbo's total landings that were made from fishing sites in the mangrove was estimated based on the landings made by fishers from this community during a season when less fishing activity is directed towards the mangrove as most fishers are able to travel farther from shore. Fitting with the seasonality identified for Antanamanimbo's fisheries, other studies performed in this area indicate declines in the fishing effort in the more productive offshore areas as a result of poor weather during the summer months (Jones, 2012). With this seasonal shift of fishing effort to near shore and mangrove fishing sites, it can be predicted that the proportion of total landings coming from the mangrove would increase during the period between November and March, increasing in the aggregate annual landings made from the mangrove by this community. If this seasonal shift could be fully and accurately included in the calculation of total landings annual landings for Antanamanimbo, the seasonal increases in the number of fishers from Antanamanimbo visiting the mangrove would likely expand the gap between these communities' annual landings from the mangrove.

Further differences in the scale of biomass harvested from the mangrove by these communities can be demonstrated by the role of mangroves as nurseries contributing to the offshore fisheries that are utilized by Antanamanimbo. Mangroves are able to provide shelter and food for juvenile fish of various species which then migrate to areas outside the mangrove or are consumed by piscivorous fish which in turn may be captured by fishers outside the mangrove (Barbier, 2000; Mumby, 2006; Mumby et al., 2004; Nagelkerken et al., 2000; Primavera, 1998a). These represent a small number of the pathways

through which biomass from a mangrove forest contributes to coastal fisheries. In the case of Antanamanimbo, even the landings that are made in fishing sites offshore and well away from the mangrove may be at least partially dependent upon primary production that has occurred in the mangrove. As a result of this transfer of biomass to fish stocks outside the mangrove, the role of mangrove forests in supporting both diets and incomes in Antanamanimbo must be at least marginally larger than the contributions can be directly identified by this case study.

Determining landings and household consumption from survey data in artisanal fisheries may not provide a perfect or precise representation of the total annual values , but surveys have been shown to provide an accurate approximation for household catches and consumption (Kuster et al., 2006). So, although seasonality in fishers' activities and challenges relating to the use of survey data may introduce some inaccuracy into this case study, these results can be counted upon to indicate the differences that exist between levels of resource use in these two communities and their implications in examining reliance upon mangrove ES.

5.1.3 Fishing Effort and Technology

Some of the differences in the scale of landings from the mangrove made by Antanamanimbo and Marofihitsy can be explained by Antanamanimbo's use of improved fishing technologies, as well as the amount of time and effort that individual fishers from this community invest in harvesting mangrove resources. Local knowledge and traditional practices contribute to some of these differences, along with the specialization of productive activities in Antanamanimbo. However, the potential for further technological innovation in both communities could have implications for what future levels of resource extraction are possible from this mangrove.

Although a smaller number of households from Antanamanimbo were recorded as fishing for crabs in the mangrove in the week before surveying, it is possible that a larger number of individuals from each household were available to fish in the mangrove. This may result from fishing being the primary occupation of this community, whereas in Marofihitsy a greater proportion of labour is invested in the activity of farming. More individual fishers visiting the mangrove per household would increase the potential number of crabs that may be caught.

Fishers from Antanamanimbo use boats to access the mangrove, while survey respondents in Marofihitsy did not report that any members of their community used this method of transportation

when fishing. Travelling through the mangrove on foot is particularly challenging due to flooded channels, deep mud, dense vegetation (often covered in the sharp shells of molluscs), the vigorous activity of mosquitoes, and the limitations on time imposed by the tides. By using boats to travel quickly to fishing sites in the mangrove, the residents of Antanamanimbo are able to extend the amount of time they have available to fish. Extended travel times to reach some of the fishing sites in the mangrove indicate that fishers from Antanamanimbo are able to travel deeper into the mangrove and are able to distribute their fishing activity over a wider range of locations. This gives the potential to access a greater number of crabs and the option to catch fish from a greater number of mangrove channels.

In the case of fishers from Antanamanimbo, those targeting finfish in the mangroves benefit from access to improved fishing technology and traditional fishing experience available in this community. The use of boats allows the same benefits as those enjoyed by Antanamanimbo's crab fishers when visiting the mangrove (longer fishing times and access to a greater area of the mangrove). While the methods for harvesting crabs are the same between the two communities, Antanamanimbo's use of nets, as well as hook and line fishing, provides a distinct advantage to fishers from this community compared to those from Marofihitsy.

As fisheries in both communities may be considered relatively labour intensive the particular skills of individual fishers become an important component in individual landings (Liese et al., 2007). The accumulated experience of years spent fishing that has been passed down from generation to generation Antanamanimbo would also contribute an edge to the skill sets of fishers from this community. As a community having heritage rooted in farming, the Masikoro people of Marofihitsy have less historical experience fishing. Some households would have moved to this community from farther inland in order to gain access to the nearby marine resources (Cripps, 2009). These relatively new fishers are likely to have a very different skill set relative to the Vezo people of Antanamanimbo.

The absence of fish or crab traps in the mangrove fisheries of both communities is a notable component when considering the time and effort invested in these activities. In many parts of the world, crab traps are a key component in commercial and subsistence crab fisheries (Bonine et al., 2008; Ewel, 2008). Scientists commonly use traps to capture *Scylla serrata* and other mud crab species when performing studies in mangrove ecosystems (Ewel, 2008; Hill, 1975; Robertson, 1989; Williams and Hill, 1982). Also, fish traps are used in tide dominated fisheries, such as those in mangrove forests, and are present in artisanal fisheries on the coast of the African mainland (Fulanda et al., 2009). In many cases these traps require relatively simple technology and could be easily adopted by fishers in this area. It can be

assumed that the adoption of these types of technology could be effective in improving the catch per unit effort in the mangrove fishery.

The absence of fish and crab traps may be a factor that reduces the per fisher biomass removal from the mangrove in this area. As is made evident by the difference in landings between Antanamanimbo and Marofihitsy, the availability of improved fishing technology allows for increased exploitation of mangrove resources. This is comparable to the impacts of technological changes in a range of other fisheries, such as the adoption of larger motorized fishing fleets with more efficient styles of nets and onboard processing of catches (Valdemarsen, 2001). Even in artisanal fisheries, the adoption of light-weight and long-lasting synthetic nets has allowed fishers to reduce labour, time and monetary investments in repairing or replacing nets and to increase landings (Busilacchi et al., 2013; Valdemarsen, 2001; Williams et al., 2008). The adoption of new technology has allowed increased exploitation of fisheries and encouraged the need to fish down food webs, in pursuit of smaller and formally less desirable species, in order to maintain landings (Valdemarsen, 2001). However, in some cases this may be compensated for by technologies that allow for selective or more responsible harvesting in order to maintain stocks of target species and to decrease bycatch (Valdemarsen, 2001). The relatively labour intensive methods and technology used in both communities' crab and finfish fisheries may contribute to maintaining the stability of current stocks for mangrove resources by physically limiting individual fishers' possible total landings.

5.2 Income and isolation

The levels of income and the degrees of isolation facing Antanamanimbo and Marofihitsy are important factors in the discussion of these communities' metabolisms and their reliance on mangrove ES. Household incomes can have a direct impact on human well-being and in both communities income generation is intimately linked to mangrove resources (Howell and Howell, 2008).

The relationship between the level of resource use and the size of household incomes is comparable to the results found in a previous study where poorer households were shown to have a greater reliance on environmental resources while wealthier households extracted and exported these resources on a greater scale (Cavendish, 2000). Interestingly, the scale of the difference in mangrove resource extraction and sales between the two communities does not correspond to a similarly large difference in their levels of well-being. A marginal increase in educational attainment, quality of diets and material

well-being occurs with an exponential increase in resource extraction and monetary exchanges when comparing Antanamanimbo and Marofihitsy. This difference between the levels of resource extraction and benefits to well-being in these communities suggests that the negative impacts from market demand and the overexploitation of mangrove resources may outweigh the benefits that are derived in the economic transition toward market integration.

5.2.1 Income and Diets

Diets in Antanamanimbo are reliant on household generation of monetary incomes that are used to purchase staple foods, while in Marofihitsy household production meets a greater proportion of dietary needs and there is lower reliance on imported agricultural products.

In both communities monetary incomes provide a means of accessing food products that are not locally produced. Antanamanimbo lacks access to agricultural land; therefore, the carbohydrate and vegetable portions of diets in this community must be purchased from outside sources. In Marofihitsy, access to arable land means that at least a portion of these dietary needs may be met by local agricultural production. This difference in access to staple foods may, in part, account for the necessity of households in Antanamanimbo having a much larger monetary income than those of Marofihitsy. In both communities the purchase of non-essential or 'luxury' food products, such as sugar and coffee, is made possible through market exchanges.

This situation in Antanamanimbo is comparable to other developing communities, such as that on the Nicobar island of Trinket, that have transitioned from the domestic production of all food consumed to focusing productive activities in order to import their primary sources of carbohydrates (Singh et al., 2001). The Nicobar example is similar to Antanamanimbo in that the islanders live in a subsistence economy through which fishing, farming and hunting are able to meet their dietary protein requirements (Singh et al., 2001). However, the high exchange value for the local production of copra (dried coconut used to produce coconut oil) means that the islanders invest their time in the production and sale of copra in order to purchase rice (Singh et al., 2001). Antanamanimbo's sale of crabs and dried fish in order to purchase rice and other agricultural products is indicative of the community's transition from subsistence to market-dominated economy. In this way market integration and income generation allow this community to meet its dietary needs.

The role of incomes in meeting the dietary needs of Marofihitsy is not nearly so pronounced as that in Antanamanimbo. Although this community does not produce rice as a staple crop, households are able to grow cassava, sweet potatoes and maize thereby, reducing the overall importance of trade and income generation in order to meet household caloric needs. Some households from Marofihitsy use incomes derived from the sale of mangrove products to purchase rice, but the role of currency-dominated exchanges in this process is offset by kind-for-kind bartering to exchange mangrove products for agricultural goods.

For a number of Marofihitsy's households that reported the lowest monetary incomes, small quantities of agricultural production were sold in order to purchase non-essential food products such as sugar and coffee. Although food insecurity may be an issue for these households, their basic dietary needs were being met without participation in a larger market chain dependent on the sale of resources extracted from the mangrove or other products. In contrast, even the poorest of Antanamanimbo were dependant on access to outside markets in order to support their dietary needs.

5.2.2 Sources of Income

Marofihitsy has a more diverse local economy compared to Antanamanimbo when measured by the reported number of productive activities. Some of the negative implications of this difference can be illuminated by discussion under the lens of resilience and an argument for redundancy over efficiency. In contrast to this argument, Antanamanimbo has obtained a marginally higher level of well-being through the intensification of productive activities that puts into question the long-term viability of the current model of mangrove resource exploitation.

Although overall household incomes are lower in Marofihitsy relative to those in Antanamanimbo, in the long term greater diversity of productive activities in Marofihitsy could play a key role in sustaining well-being in this community by offering a number of livelihoods and means for the community to generate the goods and services desired by their population (Ellis, 2011). The diversity of productive activities has been argued to be a key component in the development of subsistence economies and can lead to general increases in components of well-being (Dewi et al., 2005; Ellis, 2011). Diversity in household livelihoods is also recognized as a means to maintain resilience in overcoming economic or other shocks to household productive activities or incomes (Mutenje et al., 2010). However, as the comparison between these two communities suggests, diversity of economic activities is not necessarily the sole

determinant of well-being in subsistence economies (Dewi et al., 2005). Antanamanimbo's situation can be reflected in that of communities in Kalimantan, Indonesia, where the relative abundance of a limited number of resources allows the maintenance of well-being in spite of a lack of economic diversity (Dewi et al., 2005).

The greater number of productive activities that are practiced in Marofihitsy may be the result of a number of factors. Some activities that were identified, such as the raising of crops and livestock, are not possible on the same scale in Antanamanimbo and are logical components of Marofihitsy's economic system where the community self-identifies agriculture as its primary occupation. However, low monetary values placed on agricultural products in the community and poor crop production in recent years may be factors that have forced community members to pursue alternative sources of income in order to purchase goods that are not produced within the community.

This diversity of productive activities in Marofihitsy may also be driven by the relative isolation of the community. As distances to markets, such as that in Belo-sur-Mer, would incur travel costs in addition to the prices of goods purchased it would seem logical for citizens of Marofihitsy to produce many of the goods and services required to meet local needs and to exchange these products in local markets.

The relatively small portion of overall incomes that are provided by the sale of agricultural products in Marofihitsy may result, in part, from the fact that the crops that are grown may also be used for household consumption. Many of the households responded that their sale of agricultural products amounted to only a few thousand Ariary per month or per year, stating that this small income was used to buy sugar, tobacco, or coffee. These households were not generating large incomes in order to purchase expensive consumer goods or status items; rather they were buying simple goods that enhance day-to-day subsistence existence.

Expanding the range of productive activities in Antanamanimbo is not completely limited by a lack of alternative opportunities. In spite of a lack of arable land, there are no factors opposing other productive activities, such as the operation of an epi-bar serving beverages and other products, or citizens working as carpenters to build houses for newcomers to the community, or citizens constructing and repairing *molonga*s and sailing pirogues.

A 2010 study conducted in this region indicated that fishing was the primary livelihood strategy for 100 percent of fishing households in eight of the eleven coastal communities surveyed and for 92 percent of fishing households in Antanamanimbo (Jones, 2012). This not only corresponds with the limited number

of perceived primary sources of income identified in Antanamanimbo, but also with its heavy reliance on mangrove and fishery resources for income generation.

5.2.3 Fisheries and Incomes

The significance of the mangrove's impact on the reported incomes for Antanamanimbo and Marofihitsy cannot be denied. The combined sale of fish and crabs caught in the mangrove amount to over half of each community's total annual income. The difference between the number of kilograms of crabs and fish caught from the mangrove, and their relative contributions to monthly incomes in the two communities, can be attributed to a number of economic factors.

Antanamanimbo's reported mangrove catches from the week prior to surveying were clearly larger than those made by Marofihitsy. However, particularly in the case of income derived from crab sales, the difference in the total income derived from the sale of this product is much larger than the difference in mass of reported landings. For Antanamanimbo this may be partially accounted for by seasonal variability in this community's utilisation of mangrove fisheries with crabs accounting for a greater proportion of catches and incomes at other times of the year.

Given that the populations of these two communities are essentially the same size, the differences in catches from the mangrove cannot be entirely accounted for by the dietary requirements of each population. In Marofihitsy, where the mangrove represents the key provider of dietary protein, households are not consuming all of their catches and are selling crabs and fish that are surplus to their immediate dietary needs.

If this were the case for Antanamanimbo it would be expected that households would be landing catches that are larger than those in Marofihitsy in order to make up for their community's lack of other forms of food production. However, the reported monthly incomes in Antanamanimbo are an order of magnitude larger than those in Marofihitsy. Likely, this difference is much more than is required only for the purchase of the staples rice, maize and cassava. Specialization of productive activity around fishing in Antanamanimbo contributes to this community's reliance upon monetary exchange in order to provide access to other resources that are necessary to meet the population's basic needs.

The barter system used by Marofihitsy to trade crabs for rice in inland communities may explain some of these differences present in the monthly income sources and the kilograms landed from the mangrove.

However, accounting for the true scale of impacts from this exchange on reported monetary incomes is difficult as inland communities will also pay cash for crabs and dried fish, and there are no incentives for the individuals involved in this trade to quantify and record the proportion of exchanges occurring in cash or in kind. Respondents to household surveying also did not indicate the extent to which this bartering portion of the economy was represented by trade between households within the community. Clearly this trade does play a role in local economic activities as herders may be paid in food then receive an animal of their own at the end of a year of work, but this does not quantify the proportion of food derived from the mangrove that these individuals receive or less frequent exchanges made by other households.

The difference in the scale incomes derived from mangrove sources may result in part from the levels of isolation from markets faced by each community. Antanamanimbo has easier access to a wider range of buyers for both crabs and dried fish and markets that provide higher prices for these goods. The demand for crabs and fish from Antanamanimbo encourages extraction of these resources from the mangrove on a level that is much greater than that from Marofihitsy. In other artisanal fisheries, proximity to markets has been demonstrated as a factor that is more important than human population size in causing overfishing to occur (Cinner and McClanahan, 2006).

Antanamanimbo's breakdown of finfish landings into various classes, that are based on size and quality of the fish, is an indicator of impacts from market integration on the targeting of various species, choices in the consumption of catches, as well as when and where sales are made. This example of profit-maximizing activities through the sorting and classifying of fish would encourage households to consume smaller and lower quality fish in order to preserve larger and more valuable catches for sale.

The important role of the mud crab *Scylla serrata* in the economies of each community is likely tied to the ability of fishers and sous-collectors to keep the crabs alive for many days by coating them in damp mud. In this way Marofihitsy is able to overcome some of the impacts of its relative isolation on market activity. The large investments of time and energy associated with transporting catches to Belo-sur-Mer or inland communities are offset by the premium price received for selling a fresh and unspoilt product.

Fresh fish cannot be stored in a marketable condition without some system of refrigeration. As refrigeration or freezing of fish was not an option for either Antanamanimbo or Marofihitsy, the only option for the preservation and transportation of fish to alternative markets is through salting and drying. If there were access to a means of transporting fresh fish to distant markets without spoiling, it

is likely that the sale of fish would represent an even larger proportion of incomes in both communities. This is in evidence when considering the change in price for fresh fish between 1000 Ar/kg in either community and the possible price of 2000 Ar/kg when selling to restaurants in Belo-sur-Mer. This potential change in the distribution of monetary income sources is predicted to be greater in Antanamanimbo where the majority of households spend more than half of the year fishing outside of the mangrove.

5.2.4 Isolation and Market Integration

Access to markets is one of the main factors that can be used to explain the differences in the level of mangrove resource extraction between Antanamanimbo and Marofihitsy. Isolation and market integration have definite impacts on determining patterns of resource use and access to material goods in these two communities. In a number of studies the improvement of transportation networks has been shown to have a direct impact on local economic activities, levels of resource extraction, and community well-being (Dewi et al., 2005; Liese et al., 2007).

Patterns of Resource Use

Marine products sold by fishers and sous-collectors from Antanamanimbo can make their way to markets as far away as the capital, Antananarivo, or overseas in the case of shark fins and sea cucumbers. The range of opportunities for the sale of marine products from Antanamanimbo manifests its impacts through the scale of trade in these products and their dominance of the productive activities that are pursued in this community.

The decision to pursue the harvest of marine resources, a field where Antanamanimbo's households have a comparative advantage, is not driven solely by a subsistence pattern of catch and consumption, rather they are strongly influenced by the demands of external markets into which they are integrated (Liese et al., 2007). This influence of market integration is clearly exemplified by the fishery for shark fins in Antanamanimbo and other coastal communities. Shark fins are a highly valuable commodity that are sold to markets in Asia, and the shark nets used by in this region, known as *jarifa*, represent a considerable monetary investment on the part of fishers (Cooke, 1997; Gough et al., 2009; McVean et al., 2006). Although the meat of landed sharks is consumed after the fins have been removed, it should be noted that it is considered to be an inferior and less desirable as food when other marine products are available. Sharks would not likely be targeted by subsistence fishers in this region without the high

price placed on their fins, reported as a mean of 104 000 Ariary or 52 USD$ per kg received by Malagasy fishers (McVean et al., 2006).

The targeted fishing for sharks and the scale at which other marine products are exported from this community are indicative of a more 'developed' level of market integration on the part of Antanamanimbo when compared to Marofihitsy. However, the targeting of high value species is not the only impact that market integration has on fisheries, but the proximity of artisanal fisheries to major markets leads to a decrease in catch per unit effort in artisanal fisheries (without considering individual species), indicating the potential degradation of marine resources as a result of overharvesting (Liese et al., 2007). This is an essential component in generating incomes in this community, which are required to meet the basic needs of the population as well as accounting for increased access to material goods and higher material well-being.

Patterns of Exchange

The physical isolation of Marofihitsy definitely places this community in a position of reduced integration into national and international markets, relative to Antanamanimbo. For many households in this community, limited market integration may be one of the factors explaining why monetary exchanges were limited to the local sale of small quantities of agricultural produce in order to purchase tobacco or sugar brought in from outside the community. In these cases household allocation of productive activities appear to be solely dedicated to those subsistence activities where the results of labour are directly consumed by the household rather than traded in a market context in order to access other goods and services.

Limited financial resources at a household and community level would encourage the practice of kind-for-kind bartering as a means of exchange within Marofihitsy. Given the short distances over which kind-for-kind exchanges are able to occur with the community and the small investments of time that are required, this system may be less reliant on the benefits that formal currency has as a means to store and transfer value (Gregory, 1997).

As with other communities seeking to improve the quantity and price of goods that they export, the improvement of Marofihitsy's transportation infrastructure could have a large impact on local incomes (Halafo et al., 2004). However, given the current position of mangrove resources as highly valuable commodities in local markets and the example of higher resource extraction by Antanamanimbo,

increasing transportation and market integration could contribute to increased extraction of mangrove resources by Marofihitsy and degradation of this ecosystem.

5.2.5 Non-essential Material Goods

Comparing household ownership of non-essential material goods illuminates differences in the level of income and access to markets for each community. The presence of non-essential material goods can be indicative of disposable income and the access to technological advantages that aid in the pursuit of productive activities and improve quality of life.

The presence of particular assets as a measure of household wealth has been used as an indicator of household well-being through correlation with productive activities, household food security and the growth of children (Bashaasha et al., 2006; Takasaki et al., 2000; Wamani et al., 2004). Material assets that contribute to household productive capacity can positively influence incomes and household resilience in the face of economic shocks (Mutenje et al., 2010; Takasaki et al., 2000).

The greater number of consumer goods possessed by households in Antanamanimbo provides evidence of the impacts that higher incomes and access to markets have on the community. In particular, the existence of generators in the community indicates a higher level of economic development and market integration. Not only are generators expensive to purchase initially, but they also require household integration into complex market and supply chains in order to obtain the fuel and parts necessary for their operation. Other assets for which there are notable differences between the communities are cell phones and televisions. Cell phones may be recharged using small solar panels and are not dependent on generators for use, leading to the ownership of one cell phone in Marofihitsy at the time of this study. The adoption of cell phones in greater numbers by Antanamanimbo may not only be a result of higher household incomes, but may be a factor contributing to the growth of household incomes by increasing fishers' access to up-to-date market information and therefore improving their ability to operate efficiently within the market system (Abraham, 2006; Aker and Mbiti, 2010; Overå, 2006). One of the households with a television in Antanamanimbo did not own a generator and therefore could only use the television for decorative purposes or as a status symbol at the time of surveying. The absence of generators and televisions in Marofihitsy results not only from limited capital for their initial purchase, but also the lack of access to the resources for their continued use.

5.3 Shelter, Fuel, and Lumber

Shelter is a basic need and as a result the status and construction of homes, access to building materials, and fuel for cooking and heating are important indicators for human well-being. Antanamanimbo is entirely dependent on the mangrove for providing the lumber and fuelwood. While Marofihitsy, which has lower access to non-local resources, does not obtain any fuelwood or lumber from the mangrove. The set of mangrove ES that is linked to these resources is not represented in the market activities of either community, yet it plays a critical role in supporting human well-being.

5.3.1 Building Styles

The use of improved building materials in construction (wood plank flooring and concrete flooring) can be viewed as indicators of increased material well-being and as displays of household wealth. Households with higher incomes and social standing within each community owned these homes. The expenditure of income on improved building materials to increase a household's material standard of living has been demonstrated to be an indicator for lower poverty and increased well-being, relative to households that cannot afford these expenses (Martins, 2007; Takasaki et al., 2000). Differences between households or communities in their prevalent building styles, materials used in construction, and the ownership of various assets can be used as strong indicators for both local natural resource use and levels of human well-being (Takasaki et al., 2000).

Differences between the average costs of construction for homes in both communities, as shown in Sections 4.3.6 and 4.5.4, provide some indication of the accuracy of using building styles and materials as indicators for a household's relative monetary wealth and well-being. Higher costs for construction in Antanamanimbo correspond with greater community satisfaction with the quality of their housing and with lower levels of damage resulting from extreme weather events.

As expressed during a focus group in Marofihitsy the members of the community were not happy with the traditional mud-walled design of their homes. Although relatively simple to construct and repair following cyclones, this design was not deemed as stable or sturdy as those buildings constructed using more wood planks or sheet metal in their design. Heavy rain, such as that accompanying a cyclone, is capable of dissolving the mud walls of homes, while high winds are capable of destroying thatched roofs. With dry weather, focus group members complained of the problems that mud walls present to maintaining personal hygiene and cleanliness. That although "[they] are not dirty people" they and their

possessions are constantly covered in dirt that comes free from the mud walls. The focus group commented on government aid in the form of building supplies that had been promised to help compensate for these issues, but had not been (and was not expected to be) delivered.

The thatch wall and roof design of homes in Antanamanimbo is popular in Vezo communities along the coast. The thatch's ability to withstand rainfall and its higher level of cleanliness relative to the mud wall design may explain the lower rates of adoption of other construction methods in Antanamanimbo. The reeds used as thatch in construction would be lighter and easier to transport to the community using the fishers' small boats rather than lumber that is not present in large quantities in the immediate proximity of this community. Furthermore, locally available lumber would need to be shaped by hand before use in construction, a labour and time intensive process that can be reduced by limiting construction to the pole and thatch design. Being located in the dry deciduous forest has given Marofihitsy easier access to quality lumber for building, although some of it may be obtained through illicit logging performed in Kirindy-Mite National Park, which borders the village. More permanent styles of construction, such as those using lumber and cement, may be less attractive to members of the Vezo community due to the nomadic nature of this cultural group. Making expensive material and labour inputs into the construction of a home does not make sense for a household that may choose to sail away and that would be unable to sell the home to obtain compensation for their investment.

At the time of surveying the presence of five households living in tents or without shelter in Antanamanimbo was the result of the recent immigration of these households to the community. It is anticipated that if the members of these households choose to remain in Antanamanimbo they would, in time, construct more permanent dwellings for themselves.

5.3.2 Lumber and Fuelwood from the Mangrove

Reliance on the mangrove for fuel and building materials provides a clear and direct link between this ecosystem and households in Antanamanimbo. It would appear that the relative proximity and ease of accessing wood resources from the mangrove has encouraged the use of mangrove products over the choice to purchase alternative materials with proceeds from the sale of marine products.

Threat of Deforestation

Lumber and fuelwood, often as charcoal, are commonly harvested from mangroves by local communities in many areas of the world for local or industrial consumption (Naylor et al., 2002;

Nickerson, 1999; Sakho et al., 2011; Valiela et al., 2001; Walters et al., 2008). In many cases the harvest of wood products from mangrove forests has been a main driver in the decline and degradation of these ecosystems (Nickerson, 1999; Valiela et al., 2001). In the nearby Mangoky River delta, human action in the form of harvesting lumber by inland and fishing communities has been identified as a key factor in causing the delta's mangrove forests to decline in area by around 45 percent between 1979 and 1994 (Rakotomavo and Fromard, 2010).

Rural populations and smallholder farmers have often been blamed as key players in the issue of ongoing deforestation in Madagascar (Horning, 2012). In the Mangoky delta and other major areas of mangrove forest in Madagascar, conversion to agriculture has been identified as another major factor contributing to declines in the size and function of mangrove ecosystems (Giri and Muhlhausen, 2008; Rakotomavo and Fromard, 2010).

However, in this case, Antanamanimbo and Marofihitsy do not appear to be having a negative impact on the overall area of mangrove forest. The conversion of mangrove forest to agricultural land by households from Marofihitsy or other communities through slash and burn, or other means, was not observed to be occurring anywhere in this mangrove forest. On the part of Antanamanimbo, harvesting of wood from the mangrove occurs on a small scale and is distributed across the mangrove by the actions of individuals who collect wood when fishing.

Impacts on Well-being

Relative to Marofihitsy, Antanamanimbo's use of dead wood from the mangrove for fuel provides an interesting example of the choice to rely on mangrove ES despite the availability of alternatives, which is similar to patterns in the use of mangrove wood in Micronesia (Naylor et al., 2002). All respondents from Antanamanimbo indicated that they cook over wood fires, rather than cleaner burning charcoal or other improved fuel sources that could be purchased when fishers sell their catches in markets outside their community. It appears that the majority of this wood is derived from the mangrove in spite of the fact that many households did not indicate that they visit the mangrove to fish and harvest wood on a regular basis. The negative health effects of cooking over wood fires typically take the form of respiratory ailments (Ellegård, 1996). Improved fuel sources provide health benefits to users, particularly for women who do much of the cooking, by releasing less smoke and particulates when burned (Ellegård, 1996; Ezzati, 2005; MA, 2005a).

It would also be expected that the existence of fishers who do not visit the mangrove on a regular basis would lead to the establishment of a local market for fuelwood from the mangrove. However, as survey and focus group respondents did not indicate any sales or trading of fuelwood, it would appear that mangrove wood's relative abundance and ease of accessibility preclude any benefits to be derived through creating a market for it.

The selection of dead wood over cutting living trees from the mangrove for use as fuel is likely driven by number of factors. Firstly, the fact that dead wood would be drier than fresh wood, thereby making it easier to transport and easier to burn when cooking. Dry, dead wood from trees killed as a result of a cyclone may be easier to break into transportable pieces than flexible fresh wood, reducing the need to bring axes or other tools to harvest fuelwood when fishing. Also, as a result of the damage from cyclone Fanele and other causes, dead trees appeared to be relatively abundant and uniformly distributed within the mangrove complex.

The style of pole and thatch construction used to build most of the houses in Antanamanimbo does not rely on the use of planks and heavily shaped lumber. If this type of lumber was to be derived from the mangrove it would require the harvesting of large trees that would then be cut down to the desired size. The selection of poles from the mangrove may target trees with specific characteristics (long, straight, and not too wide), but as the walls and roof are largely composed of thatch this style of construction does not use a large quantity of wood. Furthermore, only a few of the households had constructed fences around their homes. Although the stumps of harvested trees were visible in some areas of the mangrove, the cutting of poles did not appear to be concentrated to the point of clear cutting and deforesting any area of the mangrove. At the time of surveying only one house in Antanamanimbo was under construction, although it can be assumed that the three households living in tents and the two households without shelter would be pursuing the construction of more permanent housing and use lumber from the mangrove to do so.

The harvesting of poles from the mangrove to construct drying racks for fish provides an additional indirect contribution from the mangrove to incomes in this community. Small fish may be salted and preserved using a system of brining in troughs constructed from old fishing boats followed by slow dehydration. Larger, and therefore more valuable, fish were dried by splitting then hanging the fish over a rack or protruding roof supports to dry in the sun. Without refrigeration or other methods of preservation there are few options for storing fish in a manner that would allow them to reach markets without spoiling. Given that the sale of fish accounts for over half of household incomes in

Antanamanimbo, and that large fish cure better and receive higher prices than small fish, the ability to construct drying racks is a key component of the local fishing industry. Without access to poles from the mangrove it is likely that fishers would find an alternative material with which to construct drying racks, but as access to mangrove wood is free an alternative would likely add to fishers' costs and be financially less attractive.

5.4 Regulating Services

Although they are an important component of analysis of mangrove ES, the values of regulating services from mangroves can be highly contextual. This is exemplified by the differences in replacement costs for various types of property and structures that may be sheltered by mangroves in Antanamanimbo and Marofihitsy relative to those illustrated by case studies on mangroves and shoreline protection in more heavily populated and developed areas.

5.4.1 Shoreline Protection

In past case studies and meta-analysis incorporating mangrove ES, large monetary values have been attributed to those regulatory services that can be associated with shoreline protection (Barbier et al., 2011; Barbier et al., 2008; de Groot et al., 2012; Hogarth, 2007; Kathiresan and Rajendran, 2005; Vo et al., 2012; Walters et al., 2008). The importance of mangroves in mitigating the damage of catastrophic events in coastal areas has been acknowledged in scientific literature for decades (Fosberg and Chapman, 1971). With the 2004 Indian Ocean tsunami causing massive devastation, including the loss of over 250 000 lives and billions of dollars in damage, a standard was set for measurement of coastal protection (Cochard et al., 2008; Danielsen et al., 2005; GCRMN, 2006).

However, the majority of the monetary values associated with such events have been calculated based on the cost to rebuild the damaged structures and property, the costs of rebuilding that were avoided as a result of natural coastal protection, and the costs of constructing alternatives to natural coastal protection (Badola and Hussain, 2005; Barbier et al., 2011; Barbier et al., 2008; Kathiresan and Rajendran, 2005; Sathirathai and Barbier, 2001). In simple terms, the values attributed to the level of shelter provided by mangroves are derived by comparing at a local level the extent of damage in an area with mangroves to that in an area without mangroves (Das and Vincent, 2009).

These methods may be applicable for comparisons being made for regulating services between areas with similar levels of population density, built infrastructure, and development. When making a comparison with the sparsely populated area of Madagascar, where this case study was performed the values that can be attributed to the shoreline protection ES of mangroves will be very different from those which may be calculated for the densely populated coasts of India and Southeast Asia. With relatively low costs of construction in both Antanamanimbo and Marofihitsy (see Sections 4.3.6 and 4.5.4), a value per hectare of mangrove for avoided costs to property during extreme events would not be comparable to those calculated in many other areas.

Further confounding the issue of applying values for regulating services that have been calculated in other studies are the results indicating greater damage in Marofihitsy, the community that was inland from the mangrove relative to the path of cyclone Fanele. A range of factors that may contribute to this effect has been acknowledged in the literature (Feagin et al., 2010; Gedan et al., 2011). However, the heterogeneity of ES, and the physical and social development, warrant discussion of some of the key components in the creation of this situation in Marofihitsy and Antanamanimbo.

In Antanamanimbo, the levels of damage and destruction of homes by cyclone Fanele in 2009 can be partially explained by the community's lack of shelter from rain and high winds (see Table 11). In spite of a style of construction with higher water resistance, the force of this storm would have been too great for these structures to withstand. Even some stone and brick buildings in Belo-sur-Mer were toppled and destroyed by this storm.

As mentioned in Sections 4.3.6 and 4.5.4, differences in building styles between Antanamanimbo and Marofihitsy may have a direct relationship with the ability of houses in each community to withstand extreme weather events, such as high winds and heavy rainfall. This is exemplified by the dissolving of mud walls in Marofihitsy and the higher percentage of homes in this community that were destroyed or damaged by cyclone Fanele. Homes in Marofihitsy may suffer more damage from milder weather events than those in Antanamanimbo. Minor damage to mud walls resulting from recent rain showers was evident during surveying and greater damage could be expected from more prolonged events of precipitation.

The higher levels of damage caused by the cyclone in Marofihitsy are counter intuitive when the sheltering potential of the mangrove and deciduous dry forest in the cyclone's path are compared to the exposed position of Antanamanimbo and its complete lack of shelter from the seaward side.

Interpretation of the data collected in this case study, without considering other material, would imply that the ability of this mangrove has a negative ability to provide the regulating service of shoreline protection. The assessment of shoreline protection and shelter from storms provided by this mangrove has been limited by the lack of additional data, such as the number of people injured or killed by the cyclone; quantification of other property lost, damaged or destroyed; or measurement of the height and extent of inland inundation by the cyclone's storm surge. If data on these factors could be considered it can be predicted that the Belo-sur-Mer mangrove might demonstrate the capacity to reduce the impact of large storm events or tsunamis on inland areas that are leeward of the mangrove area (Alongi, 2008).

5.4.2 Carbon Sequestration

The ongoing issue of climate change as a result of anthropogenic releases of stored carbon and the degradation of natural systems for carbon sequestration has serious implications for the continued well-being of both of these communities, as well as the global environment and human society as a whole. Mangrove forests have been receiving increasing attention as an important ecosystem for sequestering carbon and are being included in payment for ES programmes in attempts to address the issue of climate change (Alongi, 2011; Bouillon et al., 2008; Hogarth, 2007; Komiyama et al., 2008). Aside from sequestering carbon in the woody biomass of the mangrove and the substrate, it has been suggested that mangroves also export dissolved inorganic carbon into marine ecosystems where it may be stored in various forms (Bouillon et al., 2008).

Global climate change is predicted to affect agricultural production in much of the world and increase extreme weather events, potentially leading to greater variability and uncertainty in harvests (Fischer et al., 2005; Rosenzweig and Parry, 1994; Schlenker and Lobell, 2010). For the community of Marofihitsy, the implications of this change can be demonstrated by the extended drought through which farmers in the community were suffering at the time of this study. If such events become more common or increase in duration, they could have significant impacts on this community's ability to survive.

Although a degree of uncertainty exists in this area, the impacts of climate change on marine resources, through changes to ocean temperature and increasing acidity, may result in even greater negative impacts than those felt in agriculture (Cornejo, 2007; Doney et al., 2009; Doney et al., 2012; Hoegh-Guldberg and Bruno, 2010). These impacts range from the redistribution of species and their populations, extinctions, changing nutrient availability, changes in species behaviour, and the collapse of

food webs and ecosystems as acidification negatively impacts organisms that are dependent on calcification such as corals, molluscs and various phytoplankton including diatoms (Cornejo, 2007; Doney et al., 2012; Ferrari et al., 2011). These changes could have negative impacts on the fish stocks that are available for harvest by both Marofihitsy and Antanamanimbo. Increases in the frequency and severity of storm events would further limit the time available to fishers from Antanamanimbo to safely access offshore fish stocks.

For Antanamanimbo and Marofihitsy an additional impact of continuing climate change is the potential threat of sea level rise. The combined effects of thermal expansion of warming oceans and increasing inflows from melting glaciers and ice fields are predicted to result in increases in sea level by over one metre by the end of the century (Rahmstorf, 2007; Rahmstorf et al., 2007; Solomon et al., 2009). Although this may not seem like a large change given the timescale, the proximity of these communities to the current sea level means that even a small increase could ultimately lead to their displacement.

Extensive harvesting and deforestation of the mangrove would not only result in the release of carbon stored in the woody biomass of the mangrove trees (through combustion or decomposition), but it would also allow for the release of stored carbon that has been accumulated in the sediments that would have formerly been held in place by the mangrove's roots (Hogarth, 2007). However, small scale and diffuse disturbances of the mangroves through limited harvesting of wood for construction or fuel by Antanamanimbo may actually contribute to the mangrove forest's ability to store carbon (Alongi, 2011). Limited harvesting of wood may encourage new growth by trees that have been cut or new trees filling the spaces of trees that have been removed, without disturbing the sediments of the mangrove and releasing carbon stored there (Alongi, 2011). The carbon stored in the woody biomass of a mature forest is often closer to a level of stasis rather than active sequestration, which occurs at higher rates in young or growing stands of trees (Kimmins, 1997). However, accurate quantification of the amount and rate of storage occurring would require measurements of substrate accretion and monitoring of any changes in mangrove areas.

Preservation and responsible management of the mangrove forests by Antanamanimbo and Marofihitsy represent an avenue for these communities to contribute to efforts to mitigate the potential threats posed by this global issue.

5.5 Diets and Food Security

Although caloric and protein intakes are similar between communities, Antanamanimbo has higher levels of consumption and food security than Marofihitsy. This illustrates both similarities and differences in levels of human well-being in each community and the role of the mangroves in meeting these needs for both.

5.5.1 Daily Diets

The lack of significant differences in caloric intake between these communities suggests limited differences in the impacts of this component of well-being at the household level. However, Antanamanimbo's higher consumption of animal protein and lower year-round levels of food insecurity demonstrate higher dietary well-being in this community.

Dietary data was calculated assuming homogenous household consumption without differentiating caloric or protein intake based on the age and gender of household members. Nutrient requirements were calculated using formulas that are in part based on the kg of body mass for the individual under consideration. Regardless of activity level this would suggest different requirements for individuals within each household, based on their body size (Leslie et al., 1984; Pellett, 1990). At one end of the scale the caloric requirements for infants subsisting on breast milk have been calculated as 100-110 kcal/kg/day (Ogra and Greene, 1982). Although an infant's individual requirements would be less than those of a healthy adult, at the household level the requirements of the infant must also include the energy expenditure of the mother in the production of breast milk and the caloric requirements of the infant before birth (Sparks et al., 2009). However the mean caloric and protein intakes identified in this study are comparable with the values for mean protein supply (48.94 ± 1.59 g/capita/day) and calorie supply (2097.17 ± 45.18 kcal/capita/day) for Madagascar over the years 1992-2009 (FAO, 2013). This would indicate that the values expressed in this study remain accurate under the assumption of homogenous consumption by individuals at the household level.

Despite the mean caloric intakes for Antanamanimbo and Marofihitsy being similar to one another and the national averages for Madagascar, malnutrition remains a serious issue for human well-being in these communities at the household level, particularly during times of food insecurity (Oldewage-Theron et al., 2006). High levels of food insecurity have been reported as an issue for populations in rural Madagascar (Verpoorten et al., 2013). On a local scale differences in maximum and minimum

caloric and protein intake between communities may be indicative of or connected to lower household level food security in Marofihitsy. Both communities exhibited great disparity between maximum and minimum caloric intake per person, indicating high variability between diets on a household level. Yet in Marofihitsy these values were much lower than in Antanamanimbo, representing lower overall access to staples in Marofihitsy.

The protein component of diets in the two communities, in particular that derived from animal sources, is of great importance when comparing the nutritional quality of food that is being consumed. Proteins coming from animal origins have high scoring amino acid compositions and protein digestibility of 95-98 percent (Torun, 2005). These characteristics mean that the amino acids in animal source protein are readily able to be utilized by the body and efficiently contribute to metabolic activity, the maintenance and building of tissues and enzymes essential to survival (Millward, 2005). The importance of these materials is even greater in infants, growing children, pregnant and breastfeeding women. This is particularly notable for infants who require distinct essential amino acids that may be found in animal-based protein sources to achieve proper development during the first few months of growth; as later growth is slower, the recycling of amino acids is able to reduce some of the nutritional demand for particular protein variants (Millward, 2005). Although similar to plant-based proteins in their end use within the body, the difference in digestibility and ease of uptake make animal source proteins more attractive in cases where food scarcity is an issue and diversity in diets is limited.

Greater access to animal-source protein in Antanamanimbo is indicative of higher quality of diets in this community. Although Antanamanimbo lacks access to the same breadth of agricultural products that are available to the people of Marofihitsy the relative abundance of nutrient-rich marine products contributes to the maintenance of household food security throughout much of the year. The lower animal-source protein, minimum and maximum caloric intake in Marofihitsy corresponds with the higher year-round levels of food insecurity in this community.

5.5.2 Mangrove Contribution to Diets

Mangroves are essential in meeting household dietary needs in both communities through direct consumption and through providing incomes necessary to purchase staple foods. In terms of direct consumption mangroves are key in meeting human nutritional needs through the provisioning of animal protein at the household level. The role of mangrove fisheries in meeting the dietary requirements for

the citizens of Antanamanimbo and Marofihitsy can be divided into factors related to the geographic location of each community and to their prevailing economic situation.

Coastal communities in many areas of the world depend on subsistence fishing in order to meet household dietary protein needs (Labrosse et al., 2006; Sadovy, 2005). Similar to the findings presented in this case study, high levels of reliance on mangrove resources in order to meet basic needs have been demonstrated for low income and subsistence households in Kosrae, Micronesia (Naylor and Drew, 1998; Naylor et al., 2002).

Antanamanimbo's focus of productive activities on fishing, both inside and outside the mangrove, accounts for the difference in landings of finfish between the two communities. The relative abundance of fish available in this community, combined with the lack of a market for the sale of fresh fish outside of Antanamanimbo, results in households consuming fish on a regular basis. This appears to be true for most of the year, with the exception being the periods of stormy weather during *asara*. The greater availability of fresh seafood accounts for the higher levels of animal-source protein consumption in Antanamanimbo relative to Marofihitsy.

Without agriculture being practiced in Antanamanimbo, all staple grains and other non-marine based food sources must be purchased from sources outside the community. As over 90 percent of monetary incomes in this community are derived from the sale of marine resources, the currency required to purchase these other food products is directly linked to healthy marine resources (see Section 5.2.1). The role of mangrove products in providing this income, as outlined in Section 4.5.3, illustrates that the mangrove ecosystem plays an essential role in allowing this community to access dietary staples.

The fact that agriculturally-produced foodstuffs must be purchased in Antanamanimbo may also be a factor that contributes to greater consumption of animal-source foods in this community. Households that are waiting for fish to dry before selling them to *sous-collectors* may be short on currency with which to purchase other food products and only have fishery products available for consumption. This situation of resource accessibility would likely be a factor that would encourage the consumption of fish, crabs or other mangrove products as a larger portion of diets than in Marofihitsy.

In Marofihitsy, the absence of animal proteins from non-mangrove sources relates directly to the focus group response "without the mangrove we would all die". Although members of this community may be able to meet their caloric needs through consumption of their own agricultural produce (at least in non-drought years), they recognize the essential role of the mangrove in providing nutritional quality to

their diets, without which they would have difficulty maintaining their health and survival without changing their current agricultural practices. The lower availability of nutrient-dense animal products in Marofihitsy corresponds with increased consumption of beans and other plant products that contribute to higher volumes and quality of plant-source calories and protein intake when compared to Antanamanimbo.

5.5.3 Mangroves and Food Security

The identification of which mangrove products were being consumed in each community during the study period provides a unique insight into the role of the mangrove in providing a safety net for food security for each community. A common coping strategy for households that are faced with food insecurity is to limit the variety of foods that are consumed either to less expensive foods, less desirable foods or simply to the small number of food types that are available to the household (Oldewage-Theron et al., 2006). It would appear that households in Antanamanimbo and Marofihitsy actually expand the variety present in household diets, at least in the case of protein consumption. The choices made by households when harvesting mangrove resources (opportunistic or selective) is influenced by whether or not they are under pressure from food insecurity. This is comparable to other research showing the importance of wild foods as an important component in maintaining household food security (Bell et al., 2009; Bennett, 2002; Bharucha and Pretty, 2010; Brashares et al., 2004; Fa et al., 2003; Pimentel et al., 1997).

By comparing the percentage of households visiting the mangrove each month (see Section 4.4) and the percent of the population facing food insecurity each month (see Section 4.3.44.3.4) a direct correlation can be identified between these two measures. In Marofihitsy the number of individuals facing food insecurity remains relatively stable for most of the year, which corresponds with the percent visiting the mangrove year round, with only a slight increase during the hungry months of *asara*. In Antanamanimbo both food insecurity and the percentage of households with at least one member visiting the mangrove spike with the onset of *asara*. This increase in number of households visiting the mangroves was maintained through to April after food insecurity returns to normal levels.

As mentioned above (see Section 5.1.1), when considering mangroves' role in maintaining food security is interesting to note the range of species from the mangrove that are consumed by each community and annual patterns in their consumption. During the study period welks (*sakody*) and hermit crabs

(*marotondro*) were commonly identified as being consumed by households in Marofihitsy while no households in Antanamanimbo reported the current consumption of *sakody* and *marotondro*, despite the visible presence of shells from these species in middens around the community. Identification of these species as less desirable for consumption may correspond with the targeting of them by households with limited alternative protein sources during hungry months.

Residents of Marofihitsy identified *sakody* and *marotondro* as being readily available to be picked up in the mangrove and as a secondary choice for consumption after catching fish or mud crabs. In Marofihitsy the distribution of households harvesting and consuming these species did not directly relate to those households facing food insecurity at the time of surveying. Rather, they were consumed by households as a food caught by opportunity when unsuccessful in fishing for fish or crabs, when purchased because household members had not visited the mangrove, or to preserve higher value crabs and fish for sale. Although *marotondro* may be found elsewhere, the mangrove appears to be the only source of *sakody* for either community indicating the mangroves' role in providing alternative sources of food during times of need.

The beginning of the austral summer, when bad weather forces fishers from Antanamanimbo to focus their efforts fishing in the mangrove, not only coincides with increasing food insecurity in the community, but also with an increase in the population of mud crabs available to be caught. However, it is apparent that this reported increase in the number of crabs available and the greater number of fishers pursuing them is not adequate to offset the other factors responsible for creating food insecurity in this community.

In the case of Antanamanimbo, the seasonal shift between desirable foods (fish and crabs) to the, at least, occasional consumption of less desirable foods (*sakody* and *marotondro*) illustrates a shortcoming of their reliance on specialization and market integration. With reduced access to the commodity-driven exchanges that allows this system to satisfy human well-being for much of the year, Antanamanimbo is forced to shift productive activity towards the pursuit of subsistence activities that are dependent on mangrove ES rather than towards financial gain. Without the mangrove, fishers in this community would be forced to risk fishing during bad weather or sit by and go hungry. In this way the mangrove provides a safety net that allows Antanamanimbo to subsist through the hungry months in order to participate in the broader economy when fishing is able to improve.

The more diverse local economy of Marofihitsy has a lower level of market integration and appears to have a higher base level of food insecurity, but the seasonal increase in insecurity is not nearly as pronounced as that in Antanamanimbo. Year-round reliance on the mangrove as a key element in meeting nutritional needs is combined with the pursuit of a range of productive activities that allow access to food staples through small-scale agriculture and purchase made with income from other sources. Lower household incomes in this community may contribute to spending choices that favour food and meeting basic needs over the accumulation of material goods.

5.6 Cultural Services and Intrinsic Values

In both communities the mangrove forest is considered culturally important, but in the priorities and perspectives of the fishing culture in Antanamanimbo the services provided by the mangrove are more important for local identity than in Marofihitsy.

In many cases the cultural values that are attributed to natural systems by local populations play a large role in how these resources are utilized and managed (Berkes et al., 2000; Davis and Wagner, 2003; Walters et al., 2008). However, the monetary values that are attributed to these services are often relatively small when compared to the values placed on provisioning services (de Groot et al., 2012; Vo et al., 2012), or they are left uncalculated (Barbier et al., 2011). Also, when these values are calculated they tend to focus on the use of the ecosystem for recreation or tourism (de Groot et al., 2012; Vo et al., 2012). In Antanamanimbo and Marofihitsy, isolation and the rigors of daily life limit the options of tourism and recreational use of the mangrove and would imply that there is a low monetary value that could be attributed to mangrove cultural services. However, the role of cultural values in ongoing local efforts to pursue responsible management of the mangrove demonstrates that cultural services have a great deal of importance when considering human mangrove interaction in these communities.

The importance of cultural services in decision-making processes can be demonstrated by the case of the Nicobarese of Trinket, which provides an example in which the choices of a community follow the pursuit of cultural values rather than focusing on maximizing monetary incomes. The production of pork is relatively inefficient compared to the production of copra by this community, but copra production and higher incomes are forgone in favour of raising pork because it has a much greater importance in terms of social status and its role festivals and rituals (Singh et al., 2001). Although the religious importance and cultural services provided by the mangrove to residents of Antanamanimbo and

Marofihitsy do not represent a potential for income generation that can compare with extraction and sale of mangrove resources, these cultural services provide an avenue for the pursuit of conservation at the expense of monetary incomes.

In some studies, accounting for cultural services has been attempted through the quantification of intrinsic values by determining the willingness-to-pay (WTP) or the willingness-to-accept (WTA) of individuals (Horowitz and McConnell, 2002; Kenter et al., 2011; Kosoy et al., 2007; Kosoy et al., 2010; Naylor and Drew, 1998). WTP is the amount of money that a person would be willing to pay in order to conserve a set area of an ecosystem or number of individual organisms or species. WTA is the amount of money that an individual would be willing to receive in compensation for the destruction of a given area of an ecosystem or number of individuals or species.

In the context of Antanamanimbo and Marofihitsy, WTP and WTA were not adequate options for quantifying the intrinsic value of the mangroves. As these are both communities that exist as subsistence fishers and farmers disposable income is minimal or non-existent for all households. The idea of spending the limited financial resources of the community on the conservation for reasons that do not result in direct and tangible benefits to immediate survival is illogical in this context. Likewise, in this context it makes little sense for individuals or their community to receive compensation in exchange for the degradation of a system whose existence they do not control or in some cases do not even use. The inability of a WTP/WTA exercise to incorporate the importance and real values of mangrove cultural services into this assessment are comparable to the results found by Naylor and Drew during valuations of mangrove resources in Kosrae, Micronesia (1998).

However, survey responses to whether the mangrove had spiritual importance or other non-use values to household members provides a unique insight into the intrinsic values place on the mangroves by these two communities. There is similarity between these responses in that they both recognize that the creation or evolution of the mangroves was an event that occurred outside of their own control and that the complexity of this process places it outside their means to replicate the formation of the mangroves. However, the spiritual type of response links the importance of the mangrove forest to the will of a deity or spirits whose will or desire lends force to the level of reverence held by the individual household to the mangrove, or who may bring about repercussions for damage to or destruction of the mangroves. Households that responded that the mangrove has its own importance due to the complexity of its formation and regardless of the resources harvested from it demonstrate a valuation of this natural system that goes beyond simple utilitarianism and subsistence use.

5.7 Demographics and Educational Attainment

The demography of these two communities provides the basic framework upon which comparisons in human well-being are able to be made. Both communities show similar demographic trends that might impose greater pressures upon local mangrove resources as populations continue to increase. Despite the many differences in resource use and incomes between these communities, they show similar levels of education, through the proxy of literacy. Education is slightly higher in Antanamanimbo, but this difference is not on the same scale as the differences in resource extraction.

5.7.1 Demography

It is important to note that the age structures of the two communities are nearly identical in terms of their general distributions. The large proportion of people fitting into the lower age classes in both communities is indicative of a rapidly growing population. Although the lack of definitive information on deaths in either community prevented calculation of a population growth rate in this case study, it should be noted that in the similar Vezo fishing community of Andavadoaka, further south along the coast, population growth rates were calculated to be 18 percent (Epps, 2007).

High rates of population growth in coastal areas and fishing communities have been shown to have direct impacts on rates of fish stock exploitation and may result in ecological shifts in marine environments, such as that from a coral-dominated to an algae-dominated reef (Clua et al., 2005; McManus et al., 2000). In Madagascar, coastal areas with higher human population density correspond with the local degradation of marine and mangrove ecosystems (Giri and Muhlhausen, 2008; Harris, 2009; Laroche et al., 1997; Rakotomavo and Fromard, 2010). The continuation of current trends in population growth for these two communities will increase the local demand for mangrove resources in order to meet the population's needs for household consumption. Without the development of alternative livelihoods, the market demand for mangrove resources by both Antanamanimbo and Marofihitsy will also increase with the growth in human populations.

The higher maximum age in Antanamanimbo may be indicative of longer life expectancy in this community as a result of better diets, greater access to medical resources or other environmental factors. However, the relatively small size of these two communities reduces the overall significance of

conclusions that may be drawn from this difference. In addition, the near identical distribution of population between age classes in these two communities indicates that this proxy for well-being has not been notably impacted by any differences in their market integration or patterns of mangrove ES use.

5.7.2 Educational Attainment

Access to education is a key component in measures of well-being as it plays an important role in generating good social relations, but also in the capacity of providing individuals with mental tools that improve their capacity to access health, security and basic material goods (MA, 2005b; Weiss et al., 1991).

In 2009, Madagascar's adult literacy rate was reported at 64 percent, while the world average was 84.1 in 2010 (World Bank, 2012). This is nearly twice the literacy rate for any age group in either Antanamanimbo or Marofihitsy, and indicates that under this proxy for human well-being both communities are behind national and international levels.

The slightly higher levels of adult and youth literacy, adult and youth educational attainment and school attendance for youths in Antanamanimbo indicate greater current levels of well-being in terms of access to educational resources, time and income security required to pursue education. The future benefits generated by current differences in the level of education may be manifested as further improvements in well-being in Antanamanimbo that are not manifested to the same extent in Marofihitsy.

Lower educational attainment in Marofihitsy may result partially from the extent to which youths are employed in agriculture, which is the dominant occupation of the community, relative to youth employment in fishing in Antanamanimbo. Child labour can be directly related to lower formal educational attainment as time is spent working rather than in the classroom (Basu, 1999; Gitter and Barham, 2007; Psacharopoulos, 1997). This can allow children to contribute to household incomes and support other measure of well-being, but may limit their potential attainment later in life (Basu, 1999).

In Antanamanimbo, fishing is a daily activity scheduled by tides and winds, where fishers do not usually leave the community for more than 24 hours at a time. Even if children are taken fishing they regularly return to the village where the school is located and may be less likely to miss school for extended periods of time. Furthermore, during the austral summer offshore fishing is limited due to poor

weather, potentially reducing the likelihood that children will be taken out of classes to fish at this time of the year. For households in Antanamanimbo that have migrated from other areas of Madagascar or that undertake seasonal migrations, youths may face negative impacts on their educational attainment (McKenzie and Rapoport, 2011). A more educated adult population, relative to Marofihitsy, may counter some of the factors that threaten school attendance in Antanamanimbo through social and parental pressure for children to attend school.

Farming in Marofihitsy follows the pattern of *tavy* (slash and burn); this system requires all or part of families to move from the community to temporary homes near their fields where they can tend and guard their growing crops (Casse et al., 2004; Hume, 2006). As this is often for extended periods rather than short daily trips parents may be more likely to take their children with them to assist with manual labour, and if they do take their children the latter would miss the opportunity to attend school for extended periods of time. This local migration may limit the number of years that young people spend attending school through the cumulative effect of demands on their time and labour (McKenzie and Rapoport, 2011).

5.8 Population and Resource Trends: Market Integration and Mangrove Resource Use

The combination of local population growth and outside demand for mangrove products represent possible threats to the ongoing generation of mangrove ES and their ability to sustain human well-being in these communities. However, local recognition of the importance of the mangrove ecosystem has encouraged these communities to take action to ensure their continued access to these resources.

Aggregate impact of Marofihitsy on mangrove resources is lower than that of Antanamanimbo, as is made evident by the significant difference in annual landings from the mangrove by each community (see Section 4.5.1). This is a result of having access to smaller area of the mangrove and a lower number of fishing sites, as mentioned above. In addition there are limitations to finfish landings imposed by lower adoption of improved fishing technology, such as nets, that can be used in the mangrove channels. The distribution of fishing activity over a wider area of the mangrove by individuals from Antanamanimbo is offset by the larger landings made by these fishers. The targeting of the more desirable finfish and mud crabs, rather than supplementary species (*sakody* and *marotondro*), indicates

that fishing effort in Antanamanimbo is focused on the capture of species with commercial value instead of simply meeting the needs of immediate household consumption.

The differences between mangrove resource extraction in Antanamanimbo and Marofihitsy are indicative of an increase in the pursuit of profit maximizing activities as a result of increased market integration and outside demand for resources.

5.8.1 Implications of Increased Market Integration

Increasing market access has been demonstrated as a key factor in generating or meeting outside demand for mangrove resources and drives the harvesting of mangrove resources for reasons other than local consumption. The consumers of mangrove resources in these two communities must balance the benefits derived from markets and access to resources from outside their communities with the threats that are associated with increased demand on this ecosystem.

Artisanal Fisheries and Overharvesting

Although artisanal fisheries are typically seen as having a far smaller environmental impact per fisher than large scale industrialized fisheries, they are still able to have significant negative impacts on targeted resources and ecosystems. Proximity to larger markets and higher fishing pressure has led to the need for increasing fishing effort and fishing down food chains in order to maintain landings in fisheries around the city of Toliara in Southwestern Madagascar (Laroche et al., 1997). Examples of overharvesting in other artisanal fisheries can illustrate some of the potential threats posed by Antanamanimbo and Marofihitsy to this mangrove.

A common perception of collapsing fish stocks is that these collapses are primarily being driven by the actions of large and well-equipped industrial fishing fleets (Bell et al., 2008). This perception may be countered by the example of small-scale fisheries driving sea cucumber populations below the biological threshold at which reproductive capacity is able to outweigh natural mortality, leading to further complete collapse of the population without active outside management to restore numbers (Bell et al., 2008).

In the case of Belo-sur-Mer, high prices for sea cucumbers have encouraged many local fishers to enter this industry. According to key informants this has led to severe declines in local sea cucumber stocks and has forced fishers to make greater investments of time and effort in pursuit of smaller catches.

However, the increasing scarcity of sea cucumbers has increased the market price that fishers receive for their catches, encouraging continued participation in the fishery in spite of its veritable collapse.

Overfishing of sea cucumbers is not a local phenomenon, as multiple examples of over harvesting in small-scale fisheries can demonstrate the threat that artisanal fishers present to their own livelihoods (Bell et al., 2008; Perez and Garcia, 2012). A number of other studies have shown that increased outside demand for specific products from artisanal fisheries in tropical areas have changed the dynamics of fishers' activities along with affecting the relative abundance and quality of stocks of targeted species (Bell et al., 2008; Hopkins, 2011; Humber et al., 2011; McVean et al., 2006; Mwaura and Furaha, 2012; Pauly, 1997; Pauly et al., 2005; Perez and Garcia, 2012; Raberinary and Benbow, 2012; Rasolofonirina et al., 2005).

In the artisanal fisheries of coastal communities in the western Indian Ocean sharks have been caught and consumed as a meat source (McVean et al., 2006; Schaeffer, 2004). Shark meat is noted for its relatively long shelf life once preserved; however in Madagascar and Zanzibar this meat is considered less desirable compared to the meat of other fishes (Schaeffer, 2004). In the local markets considered in this case study the meat of sharks receives a lower price than that of other fish as a result of its lower desirability. In spite of the limited demand on sharks for local consumption, the high price placed on shark fins by buyers from outside the community results in fishers making large investments of labour and time in order to pursue targeted shark fishing. Although industrialized commercial shark fisheries exist, artisanal shark fisheries represent a large portion of shark landings (Bizzarro et al., 2009). Fishing pressure from artisanal fisheries has lead to declines in shark stocks with fishers landing fewer and smaller sharks (Hopkins, 2011; Pinnegar and Engelhard, 2008).

Such declines in shark stocks have led to individuals exiting this fishery in order to pursue more abundant target species, with emphasis on species, such as snapper, for which there are high market values (Schaeffer, 2004). This process of overharvesting and transition, including the choice of new target species with a high monetary value, provides a direct example of the powerful role played by market influences in the degradation of marine resources.

For both Antanamanimbo and Marofihitsy, the data presented in this case study indicate that catches from the mangrove continue to play a dominant role in generating incomes and meeting dietary needs. However, it has been noted that catches in this area have declined within recent memory and over a longer period in this region (Jones, 2012). Although these fisheries have not yet collapsed, the potential

remains for the overharvesting of mangrove resources by these artisanal fishers to severely degrade the ability of the mangrove ecosystem to meet their needs.

5.8.2 Local Response to Threats Facing Mangrove Resources

Local recognition of the important role played by mangroves in maintaining human well-being in these communities has encouraged action by local institutions to conserve and responsibly manage mangrove resources through the establishment of a system of temporary reserves.

The communities of Antanamanimbo and Marofihitsy both recognize that local population growth represents a threat through increasing demands on available mangrove resources and that rising fishing pressure has caused declines in stocks of targeted species. Their responses to this issue require a balance between the needs of current as well as future consumption. The first approach that these communities have applied is to use a system of temporary reserves in the mangrove that are intended to increase the production of high-value and high-price mud crabs. This system is based on increasing the returns to fishers in the short term through catches of more and larger crabs, while recognizing the future value of the crabs and the importance of maintaining stocks and the ecosystem that supports them. This is done without requiring payment to mangrove users in exchange for reducing their impacts on the ecosystem by foregoing harvests (Engel et al., 2008).

The establishment of temporary mangrove reserves in this area is based on a model developed for the artisanal octopus (*Octopus cyanea*) fishery involving Vezo fishers elsewhere in Madagascar (Harris, 2009; Sauer et al., 2011). Local restrictions on fishing for *Scylla serrata* has been proposed as an effective means of improving the sustainability of crab stocks that are under pressure from artisanal and commercial harvesting (Bonine et al., 2008; Ewel, 2008; Pillans et al., 2005). As demonstrated for *Scylla serrata* in Australian mangroves, the establishment of small reserves has resulted in increases in the size and number of crabs caught (Pillans et al., 2005).

Sex- selective harvesting of male crabs and live release of captured females has been shown to have positive impacts on maintaining the reproductive success and sustainability of crab stocks in fisheries where these practices have been adopted (Hankin et al., 1997; Pillans et al., 2005). The rules in Madagascar's mud crab fishery that restrict harvesting of crabs with visible eggs or when molting are intended to reduce the number of reproducing female crabs that are removed from the population. However, the lack of regulations completely restricting the harvest of female crabs and opportunistic

nature of this fishery in Antanamanimbo and Marofihitsy leads to a nearly even distribution of catches between males and females. Female crabs that are consumed in these communities were regularly observed to be carrying eggs internally, but not visible externally and therefore legal to be harvested. The adoption of sex-selective harvesting would lead to an increase in the number and proportion of female crabs in the mangrove, thereby leading to increased reproductive potential for the population and sustained availability of male crabs for harvest (Hankin et al., 1997; Pillans et al., 2005).

As the citizens of Antanamanimbo, Marofihitsy and neighbouring communities represent both the primary dependants on the mangrove as well as the primary threat to this ecosystem their action will provide the most direct means of conserving the functional ability of the mangrove and best human measure of success in this area.

6 Ecosystem Services and Management of Socio-ecological Interactions

This chapter is intended to address the third objective of this dissertation: 'To make recommendations as to the effectiveness of using an ES approach to evaluate and manage socio-ecological interactions'. The chapter begins with a discussion of some of the difficulties related to applying monetary values to ES and translating these values between different contexts. It identifies a number of the challenges that were found when attempting to perform various ES valuation techniques during the data collection phase of this case study. The chapter concludes by identifying opportunities for future research that would expand upon the data collected in the case study and would improve the utility of ES research in its capacity to guide and inform policy makers.

6.1 Values and ES

The concept of ES can provide a useful perspective when attempting to assess socio-ecological relationships, as it allows a direct avenue through which the connections between natural systems and human well-being can be communicated. However, despite the potential strengths of adopting this perspective when making resource management decisions, a number of challenges exist in performing assessments of ES and in making practical applications of the material that is available from evaluations of ES. Some of these challenges can be identified as being related to the process or perspective used in applying value to ES, such as how ES are defined, what accounting systems are used, and how monetary value and importance are reconciled. Others relate to the physical nature of ES generation and utilization, specifically the issues of spatial and temporal heterogeneity.

6.1.1 Monetary Value vs. Importance

An analysis of the monetary value of catches derived from mangroves may not be translatable into a form that accurately represents their importance to communities depending on them for artisanal subsistence fisheries. In areas where mangroves play an essential part in supporting the daily nutritional needs of local populations monetary values cannot accurately represent their importance. This is particularly evident in the communities of Antanamanimbo and Marofihitsy where alternative sources of protein are limited and even finding substitutes for staples is limited by isolation or local productive capacity.

In the case of Marofihitsy, the loss of access to the mangrove would result in the disappearance of this community. In their own words "[they] would all be dead without the mangrove". Given this context placing a monetary value on the mangrove forest would suggest that the monetary value would be representative of a value being placed on the lives of all the individuals in this community. To calculate this value based on the monetary incomes that this community generates through the sale of mangrove-derived products is illogical. It would suggest that the value of this community is 14 268 000 Ariary/year or 75 095 Ariary/person/year (USD$ 37.55 per person/year).

Further problems with assigning monetary values to ES can be identified by examining seemingly identical products under different economic lenses. As mentioned in this case study, a crab caught in Marofihitsy has a high level of importance, but a low monetary value in local markets—about 400 Ar/kg. In the fishing village of Antanamanimbo, a crab caught from the same mangrove ecosystem will sell for 500 Ar/kg locally. However, in this community each kg of crab is less important in terms of its relative importance to the local human population's nutrition than catches from the mangrove made by individuals from Marofihitsy (see Table 9). The difference in prices between villages is not a factor of greater labour input, higher scarcity or nutritional importance in Antanamanimbo. Rather it is one of lower isolation in the coastal fishing village and the presence of a more developed market economy where the crab can be sold in a broader market and where there is more money available to be exchanged at the village level.

If policy makers attempt to place a monetary value on the ES of crab production from this mangrove they must carefully consider which proxies provide the most accurate representation of the ES's importance to local populations and the broader economy. When making an economic argument for the conservation of this mangrove system the market price is the logical and seemingly easiest means of quantifying and communicating the importance of provisioning ES. These two communities and markets are located only seven kilometres apart, yet there is a 25 percent increase in monetary value for this service and this increase occurs contrary to the decline in relative importance of the ES for survival. In this case, neither price figure accurately represents the importance of the ES in question. However, the monetary value that is applied to catches and the sale of crabs appears to be a primary driver for mangrove conservation in both of these communities.

6.1.2 Heterogeneity in ES

As was mentioned in Section 5.4.15.4, heterogeneity in the distribution, generation, and use of ES can create issues in the calculation of values for specific ES and comparisons of these values between geographic areas and over time (Koch et al., 2009).

Spatial Heterogeneity

The natural world is undeniably diverse. Although similarities can exist in ecosystem function and appearance across varying geographic scales, no two areas are exactly the same. Even the opposite sides of the same tree can experience different conditions, whether these relate to the actions of other organisms or simply the amount of daylight that both sides receive, which can result in variability in biotic potential. The large and small degrees of variation within and between ecosystems result in differences in their capacity to generate ES.

Spatial heterogeneity is not limited to the natural world, but also has a large impact on the human side of socio-ecological relations. As was mentioned in the discussion of coastal protection, differences in the population density and monetary value of built infrastructure can play a large role in the calculating values for the damages caused or averted during storm events or tsunamis (Alongi, 2008; Badola and Hussain, 2005; Barbier et al., 2011; Beattie et al., 2012; Costanza et al., 1997; Das and Vincent, 2009). Heterogeneity in social conditions, including differences in social preferences and wealth, also contributes to differences in the values that are attributed to ES between geographic locations(de Groot et al., 2012). In the case of mangroves, their primary value may be attributed to tourism and recreation by people in one area (van Riper et al., 2012), coastal protection in a second (Das and Vincent, 2009), while fisheries represent their most important ES contribution to the human population in another (Badola et al., 2012).

Comparing values calculated for individual or bundled mangrove ES from studies performed in different regions, to the total annual monetary exchanges in these two communities further illustrates the issues related to spatial heterogeneity and the valuation of mangrove ES. A study performed in the Gulf of California indicated that compared to areas without mangroves each hectare of mangrove contributed additional catches of fish and blue crab valued between USD$ 25 000 and USD$ 50 000 with a median value of USD$ 37 500 (Aburto-Oropeza et al., 2008). This value is much higher than many previously calculated for a broader range of services, including USD$ 9 900 /ha/yr by Constanza et al. (1997), USD$ 27 264-35 291 /ha/yr by Sathirathai and Barbier (2001) and USD$ 750–11 280 /ha/yr by Rönnbäck (1999). When valued be their role in local markets, the total combined contributions of mangrove ES to

Antanamanimbo and Marofihitsy amounted to only 50 651 200 Ariary/year (USD$ 25 325.60 /year). Even without taking into account the area of the mangrove from which these resources are derived, this value for mangrove ES is dwarfed by those that have been calculated in studies focused on geographic areas with different socioeconomic situations.

Temporal Heterogeneity

Temporal issues in the valuation of ES can result from the natural or anthropogenically-induced variability that occurs over time in ecosystems. This can lead to changes in the quantity and quality of ES that are generated and how they may be represented in assessments of ES. In this case study, the mangrove shrimp fishery may be under-represented. Other studies performed in the area suggest that shrimp catches in recent years have been lower than normal (Jones, 2012). This temporal variability in shrimp catches may be a contributing factor in how this fishery was represented in this case study.

Seasonal variation in the use of mangrove resources was identified as a particularly important component of Antanamanimbo's interaction with this ecosystem. However, data-collection for this case study was not performed during the season when mangrove interaction was at its peak. This means that the values for Antanamanimbo's annual mangrove resource extraction were calculated based on broad monthly and seasonal approximations. Year-round data collection regarding activity in Antanamanimbo's mangrove fisheries would allow a more accurate representation of this community's reliance on mangrove ES.

Further challenges in the valuation of ES are the potential impacts on socio-ecological relations due to changes over time in population, technology, market demand and prices. Rapid population increase in Antanamanimbo and Marofihitsy may create a situation where the total values attributed to the mangrove will increase with rising demand for mangrove resources. However, if overexploitation occurs the ecosystem will be degraded, leading to reduced functionality and lower provisioning of ES. In this case, the value of the ES received will decline per person and in total.

6.1.3 Double Counting, Ecosystem Benefits and Ecosystem Functions

Clear differentiation between the ecosystem benefits that are directly utilized by humans and the ecosystem functions that allow the generation of these benefits must occur in assessments of ES. This will aid in avoiding double counting and will allow for the illumination of the important role of functioning ecosystems in supporting human well-being.

Double Counting

One of the major problems that can arise when attempting to assess ES is the issue of double counting (Boyd and Banzhaf, 2007; Fu et al., 2011). In simple terms, double counting is a mistake that can be made by counting the value that is applied to a specific ES more than once and then reporting them as an aggregate rather than as multiple representations of the same value.

Part of the risk for double counting occurs as a result of overlap between the commonly used ES classifications that were part of the MA (2005a). Particular ecosystem functions may be identified as falling under the different categories of provisioning, regulating, supporting and cultural services. However, these functions may all contribute to a single ES that is utilized by humans. Double counting will occur if the value of that single ES is attributed to each of the individual functions that support it and then those divested values are aggregated during the final accounting for values of the ecosystem.

In the case of assessing mangrove ES, double counting could occur if the value of fish and crab landings from the mangrove was used to represent the value of the mangrove as habitat for these species, then in the calculation of the mangrove's total value if the value representing habitat was added to the value of landings. This would be double counting because both the calculated values for habitat and landings by fishers are only representations of the same end service of producing fish.

The problem of double counting is not always the result of simple problems of definition or errors in accounting, but may also be caused by the inherent complexity of ecosystems, difference in methods for valuation, the exclusive or complementary natures of different ES, and variation in values over spatial and temporal scales (Fu et al., 2011). Some ES may not be amenable to monetary valuation, and leaving them out of accounts for given ecosystems may mean that reported values are under representing their true importance. This under-representation of total importance may encourage efforts to place values on a greater number of the ecosystem functions that generate specific ES. However, unless these functions are able to make contributions to end ES that are unique from one another this may only add to double counting rather than the accurate communication of a natural system's importance to human well-being.

Whatever the cause of the error, double counting is an issue for the study of ES not only because of the immediate implications of inaccuracy in a given study, but also because it may give policy makers cause to question the integrity of all work done using this perspective on socio-ecological relations.

One of the simplest solutions to the problem of double counting is adopting or recognizing a system of ES classification that focuses valuation only on the benefits that are directly consumed (Boyd and Banzhaf, 2007; Fisher et al., 2009; Fu et al., 2011). This means that monetary valuations are only attributed to ES that can be clearly differentiated from one another. The ecosystem functions that must occur in order to produce these end benefits can be represented by the value given to the end benefit. This also allows room to recognize the complexity of natural systems in which many different functions are required in order to generate a single end benefit or that individual functions may result in many benefits that contribute to human well-being.

An additional component to the issue of double counting that receives little attention in the literature is that ES can have both positive and negative impacts on human well-being. In the case of mangrove ES, the positive benefits to coastal communities through the provisioning of fish, wood, and shelter must be weighed against the negative issue of providing habitat for mosquitoes that have the potential to carry deadly diseases. If a full assessment of the ES generated by a given ES is to be performed it must recognize that not all of the ES can be counted as benefits and although ignoring this may not fit the definition of double counting it certainly is a misrepresentation of the full range of values attributable to ES.

Ecosystem Functioning

As mentioned above, the ES perspective on assessing socio-ecological relationships provides an avenue to communicate the complexity of the roles in which the different functions of natural systems contribute to the generation of end ES that impact human well-being.

Currently, there is no man-made system that can match the complex functions and range of provisioning, regulating and cultural services provided by the mangrove in this area (Hogarth, 2007). Even if there were, it is unlikely that it would have a level of efficiency anywhere near that which exists in this natural system. The importance of and the incentive to pursue conservation could be undermined by the unlikely possibility of substituting ES with future technology.

Replanting mangroves would present the option of returning ecosystem function in cases of degradation or destruction (Walton et al., 2007). But this is only a return to reliance on a natural system, not an alternative means of meeting the population's needs. Furthermore, the communities bordering this mangrove complex do not possess the resources necessary to finance a full rehabilitation of the forest. When asked what they would do if they had the money to rehabilitate a degraded mangrove, the

majority of responses were that they would not choose to spend money on replanting this ecosystem. However, they did express interest in learning how to replant mangroves and supplying some of the labour to do so. Even with the resources to rehabilitate mangroves, the people here do not believe that they would survive for the amount of time it would take for mangroves to become re-established and to restore their access to ES.

6.2 Challenges in Using Case Study Approach to ES

The challenges identified in gathering and interpreting the results when using this case study approach to the evaluation of mangrove ES can be identified as falling in two main categories. The first includes the challenges that are inherent in relying upon short-term surveying for data collection. The second involves the issues that arise when trying to compare data between different contexts.

6.2.1 Challenges in Data Collection

The use of household surveying as a data collection technique carries a number of inherent challenges to establishing a precise and accurate set of information. In this case study specific areas of inaccuracy resulted from challenges assessing temporal shifts in the use of mangrove ES, poor memory or inaccurate responses from survey participants, and the natural variability that exists in the biological systems for which questions were being asked.

Inaccurate Survey Responses

As households do not regularly record data on the catches that they make, not even keeping ledgers on how many kilograms of dried fish or crabs are sold to sous-collectors, ensuring the accuracy of this material during data collection was particularly challenging. When asked how much they catch of any species or class of fish the first response would often be representative of the largest landing that they made recently. This may be a result of a number of factors including the lack of book-keeping, that these large catches are the ones worth noting in their memory and the age-old 'big fish' stories that seem to be a staple of fishers everywhere. An additional challenge to performing an accurate quantification of landings was identifying the number of days spent fishing. Many fishers initially responded by saying that they are fishers and therefore fish every day. Questioning then had to be

modified to remind fishers of the reasons why they may not have fished every day, then determine how many days they would normally fish in a week or in a month.

As well as the lack of book-keeping, it was difficult to determine fisher's perspectives on their choice of target species and the topic of opportunity costs such as those involving alternative livelihoods or the decision to fish in the mangrove versus out at sea. It was difficult for respondents to visualize or imagine hypothetical situations, and difficult for them to provide reliable and quantifiable responses to questions asked about hypothetical situations.

Temporal Shifts in Mangrove Use

As suggested in Section 6.1.2 , temporal heterogeneity can be a challenging component in the valuation of mangrove ES. In this case study, seasonal and other changes in the use and production of mangrove resources over time introduced an element of uncertainty into the calculation of the annual contributions made by mangrove ES to maintaining human well-being in Antanamanimbo and Marofihitsy.

Migration of other fishers into the community of Antanamanimbo and local region in order to fish in the mangrove during *asara* was identified as an annual pattern in the utilization of mangrove fisheries. As these seasonal fishers of the mangrove were not present in Antanamanimbo at the time of surveying they were not identified as residents of this community or incorporated into calculations of community income, diets or resource extraction from the mangrove. Furthermore, residents of Antanamanimbo were not able to accurately quantify the size of this seasonal population fluctuation in terms of the number of households coming to their community or outside fishers visiting the mangrove. Community level population shifts could be estimated through an assessment of the number of unoccupied homes at the time of surveying. However, differentiation between seasonally unoccupied and permanently abandoned dwellings would be difficult, and would not account for the migrant households that live in tents or temporary shelters rather than more permanent structures during their stay in Antanamanimbo.

6.2.2 Comparison to Other Case Studies

As illustrated by the issues of spatial and temporal heterogeneity in the use and production of mangrove ES, the translation or comparison of values for given ES between specific case studies can be fraught with difficulties (Costanza and Folke, 1997; Vo et al., 2012).

The large differences between the local prices for specific mangrove resources in Antanamanimbo and Marofihitsy suggest some of the problems in extrapolating information from this case study to use in assessing mangrove resources in other areas. The physical differences in ES generation and societal preferences regarding their use are compounded by the variability that exists in their definition and methods that are used for valuation. The data collected by other case studies or meta-analyses varies and presents challenges to comparison based on the methods used in data collection or the calculation of values (de Groot et al., 2012). Greater challenges to comparing of ES occur in that for many ES the data simply has not yet been collected or in cases where it has been collected the information is limited or of poor quality (de Groot et al., 2012).

Some of the challenges to comparing this case study to others were made evident during data collection. Not only did Antanamanimbo make different uses of the mangrove compared to other communities in Madagascar or elsewhere in the world, but attempting to apply some of the valuation methods used in other case studies was not possible in this situation. For example, establishing a contingent valuation model for this mangrove system was not practical as local populations where not able to state willingness-to-pay or willingness-to-accept for mangrove derived ES. Local pressures relating to resource access and limited available money in these communities contributed to responses that they would not pay to maintain access to the mangrove. They did say that if the mangrove was threatened or destroyed they would want to learn how to replant it and that they would provide labour to do so, but this could not be used to calculate willingness-to-pay as a standard local market price for labour did not exist in either community.

6.3 Opportunities in Using Case Study Approach to ES

Although many challenges exist in extrapolating data from specific case studies to other areas or contexts, knowledge pertaining to how one mangrove provides ES is unlikely to have a negative impact

on understanding the function of other mangroves or in performing a meta-analysis on mangrove ES. Using the data from a local case study would help to accurately communicate the current status of resources to decision makers rather than allowing new policies to be guided by estimates based solely on information that does not represent the situation in question.

6.3.1 Local Resource Management

The particular value of this case study is the value that it may present to efforts towards the local management of mangrove resources. As mentioned above, many challenges exist when it comes to accurately translating the value of specific ES between case studies, but these challenges are irrelevant when a given case study is used in reference to the resources and communities upon which it was performed. Using a case study approach to investigate ES and their relationship to human well-being provides tools for those individuals that interact with given ecosystem on a regular basis to make informed and responsible decisions regarding resource use and management of natural systems.

The data collected in this case study should complement the establishment of temporary mangrove reserves by Antanamanimbo and Marofihitsy. Illustrating the importance of mangrove resources in providing for local diets and incomes will aid in communicating the motivation for this action to new community members, different levels of government and other stakeholders that may not have firsthand knowledge of the role played by the mangrove in supporting human well-being. This should strengthen the links between policy makers, and the values and importance that can be placed on mangrove ES (Vo et al., 2012).

6.4 Future Research

This case study has illuminated research questions for future investigation that fall into two main categories. One being research that pertains specifically to mangrove ES and knowledge gaps within this case study. The other being questions related to ES as a general field of study.

6.4.1 Research on Mangrove ES

Although a potentially infinite number of questions exist regarding the complex interrelations between ES and human well-being, there are a few particularly notable knowledge gaps regarding mangrove resources and the communities of Marofihitsy and Antanamanimbo. The gaps include the lack of information or detail regarding: the role of mangrove resources in supporting human well-being once they are exported from these two communities, the biological links between the mangrove and specific fisheries, and the seasonal shifts that occur in the generation and use of mangrove ES.

Much of the literature and work relating to coastal fisheries and marine resources in Southwest Madagascar has focused on the fishing villages located directly on the coast and where the local livelihoods are dominated by fishing (Harris, 2009; Humber et al., 2011; Jones, 2012; Laroche et al., 1997; Le Manach et al., 2012; McVean et al., 2006; Raberinary and Benbow, 2012; Rasolofonirina et al., 2005). This is a logical focus as the artisanal fishers in these communities represent the primary avenue for human interaction with these resources and a direct reliance upon them in order to meet their subsistence needs. However, mangrove resources played an essential role in generating incomes and meeting the dietary needs of inland communities that would not typically be classified as fishing villages, as is illustrated by the data from Marofihitsy. The trade network the extends inland from Marofihitsy provides another example as to the importance of marine and mangrove resources in diets of human populations that may not have been viewed as directly linked to this ecosystem by past research. The same logic applies to mangrove resources that are exported by Antanamanimbo and their roles in meeting human needs following transport to the market in Morondava and to large urban centres inland, such as Antananarivo or to markets overseas. This suggests a new direction for research into the role of mangrove ES in supporting human well-being on a broader scale.

The highly seasonal nature of mangrove fisheries in these communities represents a key component of human-mangrove interaction through temporal changes in the abundance of various target species and varying numbers of local and migrant fishers visiting the mangrove. However, the relatively short period over which data collection was performed for this case study did not allow for the precise measurement of the total annual landings made from the mangrove or account for additional fishers migrating to this community to fish in the mangrove at different times of the year. Year-round monitoring of mangrove fisheries, along with the presence and practices of any seasonally migrant fishers to the mangrove, would be a key step towards making this case study more robust and valuable to parties interested in managing these mangrove resources.

The role of the shrimp fishery in and around the mangrove is under-represented in this case study. Research related to shrimp fisheries and shrimp aquaculture is a dominant component in mangrove literature (Grasso, 1998; Nagelkerken et al., 2008; Nickerson, 1999; Primavera, 1998a; Primavera, 1998b; Primavera, 2000; Rönnbäck, 1999b; Rönnbäck et al., 2003; Thu and Populus, 2007). In addition to this, commercial trawling for shrimp in this area and seasonal artisanal shrimp fishing by coastal villages have been identified as important factors influencing local marine ecosystems and human-mangrove interaction in this area (Jones, 2012). A more detailed investigation of this fishery and its role in the diets and incomes of Antanamanimbo and Marofihitsy would expand upon an important dimension in their use of mangrove ES.

6.4.2 General ES Research

The role of ES in supporting cultural identity and well-being through cultural services in subsistence economies remains relatively unexplored and un-quantified in much of the current literature on the subject. Assessments of cultural services have been performed in the context of developed societies through evaluations that focus on ES that are associated with non-consumptive forms of recreation and tourism (such as hiking), or intrinsic values placed on the existence of natural areas or particular species (Jones-Walters and Mulder, 2009; Lautenbach et al., 2011; van Riper et al., 2012). However, monetary valuations of cultural ES have been demonstrated to break down in contexts where deeper social values are placed on particular ecosystem functions (Kenter et al., 2011).

Future research attempts to assess the values of individual ES should attempt to focus on those services that are not already represented by large commercial interests. In the case of mangrove ES, fisheries represent a field that has been investigated on a number of scales and in different economic and ecological contexts. The extent of this type of focus means that there may be adequate data to overcome some of the issues in the spatial and temporal heterogeneity in the provisioning and use of this ES. This makes assessments of mangrove fisheries easier and more accurate while encouraging their position as a focal point for studies of this ecosystem. Topics such as fuelwood harvesting from the mangrove or cultural services (as mentioned above) have not been studied in as many contexts, and as a result it is more difficult to make comparisons between studies of these ES in different regions and accurately estimate their values. In order to provide policy makers, academics and the general public with a more robust picture of the scope and complexity of socio-ecological relations, future studies of ES should make an attempt to focus on those ES that are not yet widely represented in the literature.

6.4.3 Economic Transitions

This case study has provided a unique insight into how patterns in resource use intensity may shift with market integration and the specialization of productive activities. However, focus on mangrove ES during household surveying and focus groups resulted in the exclusion of information on Marofihitsy's agricultural sector from the data collected. Future studies in these communities could focus on the role of local agricultural production in meeting dietary needs and to what extent this balances or is complemented by incomes and food derived from the mangrove.

Assessment of differences between these two communities in terms of their relative specialization of productive activities is limited by this knowledge gap regarding agricultural activities in Marofihitsy. This specialization of labour and focusing of productive activities may by a key component in the shift between subsistence economies and greater levels of market integration. Its relevance to the management of natural resources is suggested by the differences in mangrove resource extraction between these two communities. This topic may be of particular interest for future investigations into economic transitions and communities' social perspectives on their relations to local ecosystems. Also, it may illuminate some of the underlying factors that contribute to resource degradation as perspectives shift from viewing ecological functions as essential to meeting immediate and basic needs, to seeing the extraction and use of ES as one step in an indirect chain that allows access to other resources.

7 Conclusions

The use of an ES framework in this case study illustrates the importance of natural systems for the maintenance of human well-being and provides insights into the complex relationships between human societies and their surrounding environments. This study provides a valuable tool for responsibly guiding conservation and resource management decisions, by identifying the potential environmental and social impacts associated with changes in market integration and corresponding increases in resource consumption.

The communities of Antanamanimbo and Marofihitsy directly rely on the same set of mangrove ES to provide household incomes and to meet dietary needs, despite exhibiting large differences in their social metabolisms. The majority of annual incomes in Antanamanimbo and Marofihitsy are derived from the sale of crabs and fish caught in the mangrove. With limited diversity in local diets, direct consumption of catches from the mangrove provides a significant component of important nutrition in the form of animal-based protein. For Marofihitsy, the mangrove is the source for nearly 100 percent of the animal-based protein consumed in the community. In Antanamanimbo, the sale of catches from the mangrove generates the household incomes that are necessary for citizens of this community to purchase the staple foods that make up the balance of local diets. In both communities the mangrove was also viewed as a safety net, on which residents could rely for food and income during difficult times.

Antanamanimbo's greater market integration contributes to significantly higher household incomes and higher rates of resource extraction from the mangrove, relative to Marofihitsy. Higher incomes have allowed the accumulation of more material goods in Antanamanimbo, the result being that Antanamanimbo has a higher social metabolism than Marofihitsy. This has increased the intensity of mangrove resource extraction and created a greater risk for the mangrove ecosystem to be overexploited, which would reduce its capacity to generate ES. Furthermore, income generation has become heavily dependent on a limited range of productive activities, most notably the capture and sale of a single species of crab from the mangrove (*Scylla serrata*). This means that livelihoods are particularly vulnerable to any changes in the mangrove ES that support these productive activities. In this manner, market integration has both increased the demand for mangrove resources and increased the threats to the viability of a system that is dependent on those same mangrove resources.

In addition to the role of mangrove ES in supporting income and diets, the maintenance of human well-being in Antanamanimbo and Marofihitsy relies on a number of mangrove ES that are not represented

by local market exchanges. In Antanamanimbo, lumber and fuelwood from the mangrove are goods that are essential for citizens to meet their basic needs, but for these products there are no local markets and the communities do place monetary values upon them. Regulating and supporting services, such as carbon sequestration and control of shoreline erosion, are not easily represented in a market context, but represent important pathways through which the functioning of natural systems maintains the physical survival of Antanamanimbo and Marofihitsy. These ES support and enhance the continued existence of each community's unique cultural identity and their citizens' psychological well-being.

Despite the large differences in income, market integration, and social metabolism that exist between Antanamanimbo and Marofihitsy, these communities show no significant differences in levels of human well-being. Antanamanimbo is only slightly ahead of Marofihitsy in terms of educational attainment, hygiene, and dietary quality and quantity. The near identical distribution of age structure for each community shows that they are facing the same high rate of population growth and have no appreciable differences in life expectancy. This suggests that, although local incomes can be improved by harvesting and selling more mangrove resources, increasing the extraction of mangrove resources beyond the levels required to meet basic needs will yield only marginal improvements to human well-being.

This case study illustrates that human well-being is multi-dimensional, relies heavily on natural systems, and has many components that are not accounted for by market systems. By drawing on the ES perspective this investigation illuminates the multitude of pathways through which functioning mangrove ecosystems contribute to the maintenance of well-being, and the roles of mangrove ES in local economic activity. This approach provides qualitative and quantitative insight into the impacts of market systems on the valuation of nature and the corresponding responses in patterns of resource use. Notably, the market value attached to particular ES and their importance to well-being are not the same. This means that actions to conserve natural systems and maintain human well-being cannot rely completely on market systems and monetary values to accurately represent the importance of ES to the satisfaction of societal needs.

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Appendix

This appendix contains the following document:

- A draft of the household survey used in the communities of Antanamanimbo and Marofihitsy.

Survey on Mangrove Use and Household Well-being

Draft for consultation with Blue Ventures staff and community members

Identification and analysis of the linkages between ecosystem services, mangrove forests and human well-being in Western Madagascar

HOUSEHOLD IDENTIFICATION	
1. No. SECTOR	
2. HOME No.	
3. NUMBER OF PEOPLE IN HOUSEHOLD	

DATE (DD / MM / YY)	_____ / _____ / _____	**INTERVIEWER**	

Please, one copies of the informed consent form must be signed by the participant before the survey.

SURVEY NUMBER _____ / _____ / _____	I completed the informed consent process with the participant and attached the letter signed or with indication of oral consent. ☐ **Yes** ☐ **No**

Comments:

I. HOME GENERAL INFORMATION - A. HOUSEHOLD MEMBERS AND EDUCATION

	1) What are the age and sex of all people who usually eat together in this household? RECORD THE SEX AND AGE OF ALL THE PEOPLE WHO EAT in this household. Include infants and the elderly.		**2)** What level of education completed (...)? AT WHAT YEAR DID THIS PERSON LEAVE SCHOOL	**3)** "(...) Can read and write? **0 = No** **1 = Yes**	**4)** Has this person worked in agricultural in the last 12 months? **0 = No** **1 = Yes**	**5)** Has this person gone fishing in the last 12 months? **0 = No** **1 = Yes**	**6)** Who is the person best informed on household mangrove interaction?
NO	**SEX**	**AGE**	**YEAR NUMBER**	**CODE**	**CODE**		**NUMBER**
1							
2							
3							**7)** "The interview was done with this person? **NO = 0** **YES = 1**
4							
5							
6							
7							
8							
9							**CODE**
10							
11							
12							
13							
14							

8) The place where the household lives is (...)			**9)** How much is your monthly rent?	**10)** How long have you lived in the community? RECORD YEAR ARRIVED.
1. Owned and fully paid	4. Transferred or borrowed	5. Rent it -> 1B		
2. Owned but still paying -> 1B	5. Inherited or donated	6. Other		
CODE			**ARIARY**	**YEAR**

Comments:

II. WORK AND ECONOMICS - 1) SOURCES OF INCOME AND ASSETS

A. SOURCES OF INCOME				CODE
11) What is the main occupation of the men in your household?	1. Fisher (Fish) 2. Crab fisher 3. Store owner	4. Carpenter 5. Fish Trader 6. Farmer	7. Herder 8. Labourer 9. Other ___?	
12) What is the main occupation of women in your household?	1. Fisher (seasonal) 2. Fisher (daily) 3. Fish trader	4. Sales (non-fish) 5. Labourer 6. Farmer	7. Domestic Worker 8. Other ___?	

13) What is the main source of income (money) in your home? 13B) What is the second?	**Most important source**	**Second source**

NO MENTION OF ALTERNATIVE ANSWER LET PARTICIPANT SPONTANEOUSLY.

1. Sale of fish
2. Sale of crab
3. Sale of shark fins
4. Sale of other marine products
5. Fish trader
6. Crab trader
7. Sale of animals / animal products
8. Day labour in agriculture (used for farming)
9. Working in 'aquaculture' (sea cucumber)
10. Sale of firewood or charcoal
11. Independent work (driver, carpenter, casual workers, etc.).
12. Government employee (teacher, health worker, and administration)
13. Employee of private company or NGO
14. Craft Sale
15. Sale of wild produce (fruit, etc.).
16. Small business (small scale)
17. Business (larger scale)
18. Grants for home, jobless benefits
19. Remittances from migrants (within or outside the country)
20. Other (specify)

14) How many household members earn money?	**NUMBER**	
15) Has any household member has been paid for work during the last month? **0 = NO 1 = YES**	**CODE**	

Household member NUMBER	Days worked in the last month	Daily wage (Ariary)	Total income from wages
A.			
B.			
C.			
D.			
E.			

Comments:

B. OTHER MONTHLY INCOME			
16) How much did the family earn for these activities in the last month?	**Ariary**		**Ariary**
1. Sell products in market		**8.** Livestock sales	
2. Craft Sale		**9.** Midwifery	
3. Sale of fish		**10.** Selling vegetables or fruit	
4. Sale of crab		**11.** Land Lease	
5. Sale of food (dining)		**12.** Carpentry	
6. Family Remittances		**13.** Other Income	
		TOTAL	
17) Have there been any other major sources of income in the last year? (Such as making and selling a pirogue)		**ACTIVITY**	

C. ASSETS		**18)** Do you currently have any of these goods at home? **0 = NO 1 = YES**					
Molanga		Radio		Plow		Shark net (jarifa)	
Television		Cell Phone		Zebu-cart		Sailing pirogue	

D. STABILITY / VULNERABILITY - ADVERSE SITUATIONS

19) What have been the main difficulties or problems in the past 12 months?

1. Loss of employment / reduced salary
2. Low selling price of crab
3. Low sale prices of fish
4. Loss of fishing days
5. Loss of any crop
6. High food prices
7. Decreased demand for crab
8. Decreased demand for fish
9. Sickness / health care costs
10. Death of household members
11. Loss of aid in cash or kind (remittances)
12. Debt Repayment
13. Drinking water irregular/uncertain
14. Environmental problems (pollution, industries)
15. Droughts, floods, heavy rains
16. Land dispute
17. Another problem (specify)

99 - If you do not mention the 2nd or 3rd difficulty

NO MENTION OF ALTERNATIVE ANSWER LET PARTICIPANT SPONTANEOUSLY, THEN ASK THE 3 MOST IMPORTANT

19A) 1st Difficulty	
19B) 2nd Difficulty	
19C) 3rd Difficulty	

20) Has(…) meant to the home a decrease or loss of:

1 - Revenue normally received
2 - Accumulated wealth
3 – Social well-being
4 – There is no loss

1st CODE	
2nd CODE	
3rd CODE	

Comments:

III. FOOD

21) In the past week, has your household produced what they needed for food at home? **1. Yes 2. No 3. Partly**	**22)** In the past week has this household consumed fish? **NO = 0 YES = 1**	**23)** In the past week has this household consumed crab? **NO = 0 YES = 1**
CODE	**CODE**	

A. FISH AND PROTIEN CONSUMPTION								
24) In the past week, what types of marine creatures were consumed by this household? **NO = 0 YES = 1**		**25)** In the past week, what quantity of _____ was consumed by this household?		**26)** In the past week, what quantity of _____ was purchased by this household?		**27)** In the past week, what quantity of _____ was harvested by this household?		**28)** In the past week, the fish harvested were used for: **1.** Household consumption **2.** Local sale **3.** Non-local sale **4.** Household consumption (higher) and sale (less) **5.** Sale (higher) and household consumption (less)
TYPE	**CODE**	**KG**	**NO.**	**KG**	**NO.**	**KG**	**NO.**	**CODE**
1. Shrimp (crevette)								
2. Mangrove crab								
3. Mangrove fish								
4. Near-shore fish								
5. Reef fish								
6. Whelks (‘sakody’)								
7. Hermit crabs (‘marotondro’)								
8. Divike								
9. Bonzike								
10. Octopus or Squid								
11. Other, what?								

Comments:

29) In the last 7 days, how many days consuming each type / group of food?		**30)** How much of each food does your household normally consume at a time?	**31)** What was the main source of the type / group of food during the past 7 days? **1. Grown/harvested by household** **2. Market purchase / local store** **3. Work for food** **4. Gift neighbours / family**
	DAYS	**KG or NO.**	
1. Beans, peanuts and coconuts			
2. Fish, shellfish, octopus, shark			
3. Chicken, goat, pork, beef, eggs			
4. Milk, cheese, cream and other dairy			
5. Cooking oil			

B. RICE AND BEANS

32) Last week, how many kapoaka of rice were cooked at home?	**33)** In a week, how many kapoaka of rice are *usually* cooked at home?	**34)** Where does the rice normally eaten at home come from? **1.** Purchased **2.** Given **3.** Traded for **4.** Farmed IF MORE THAN ONE SOURCE LIST MAJOR TO MINOR	**35)** Last week, how many toko of cassava were cooked at home?	**36)** In a week, how many toko of cassava are *usually* cooked at home?	**37)** Where do the beans normally eaten at home come from? **1.** Purchased **2.** Given **3.** Traded for **4.** Farmed IF MORE THAN ONE SOURCE LIST MAJOR TO MINOR
KAP	**KAP**	**CODE**	**TOKO**	**TOKO**	**CODE**

C. MONTHS OF ADEQUATE SUPPLY OF FOOD (MAHFP)	**CODE**
38) In the past 12 months, there were months that did not have enough food to meet the needs of the household? **0 = NO 1 = YES**	

39) What were the months (in the last 12 months) in which there was not enough food to meet the needs of the family?

July	**June**	**May**	**April**	**March**	**Feb**	**Jan**	**Dec**	**Nov**	**Oct**	**Sept**	**Aug**

Comments:

IV. MANGROVES

A. INTERACTION WITH MANGROVES					
40) Have you visited the mangroves in the past week? **NO = 0 YES = 1**	**41)** What was the purpose of your visit? **NO = 0 YES = 1**		**42)** How many times did you visit the mangrove for this purpose in the last week?	**43)** How far do you travel for each activity?	
CODE	**ACTIVITY**	**CODE**	**NO. OF VISITS**	**TIME**	**DIST.**
	1. Fishing ->B				
	2. Fuel (firewood or charcoal) ->C				
	3. Lumber (bois) ->D				
	4. Honey (miel)				
	5. Travelling through				
	6. Other _____				

B. FISHING IN MANGROVES								
A. What species do you fish for in the mangroves? **NO = 0 YES = 1**		**B.** How much did you catch in the last week?	**C.** How much do you catch in a good, bad and normal week?			**D.** Do you sell your catch? **NO = 0 YES = 1**	**E.** How much of your catch do you sell?	**F.** What price do you receive?
SPECIES	**CODE**	**KG or NO.**	**GOOD**	**BAD**	**NORM.**	**CODE**	**NO. or KG**	**ARIARY**
44) Crab								
45) Shrimp								
46) 'Provandy' (SF-NS)								
47) 'Fia Frire' – salted								
48) 'Fia Vary' – (BF-S)								
49) Tuna (thon)								

Comments:

C. FUEL COLLECTION FROM MANGROVES							
50) Do you collect firewood from mangroves? **NO = 0 YES = 1**	**51)** How many trees did you collect in the past week?	**52)** What are the most, least and normal amounts that you collect in a week?			**53)** Do you sell what you collect? **NO = 0 YES = 1**	**54)** How much do you sell?	**55)** What price do you receive?
CODE	**NO.**	**MOST**	**LEAST**	**NORM.**	**CODE**	**NO. or KG**	**ARIARY**

D. LUMBER COLLECTION FROM MANGROVES								
56) Do you collect lumber from mangroves? **NO = 0 YES = 1**	**57)** How much did you collect in the past week?		**58)** What are the most, least and normal amounts that you collect in a week?			**59)** Do you sell what you collect? **NO = 0 YES = 1**	**60)** How much do you sell?	**61)** What price do you receive?
CODE	**KG**	**NO.**	**MOST**	**LEAST**	**NORM.**	**CODE**	**NO. or KG**	**ARIARY**

E. OTHER USES OF MANGROVES					
62) Is it important for mangroves to exist in this region? **NO = 0 YES = 1**	**63)** Why are mangroves important? FIRST AND SECOND REASONS		**64)** Do you normally visit mangroves alone or as a group? **1.** Alone **2.** With family **3.** With others	**65)** Do you visit the mangroves for leisure or any other reason? **0.** No **1.**.Leisure **2**.Other reason _____?	**66)** Are the mangroves important to the ancestors or for other spiritual reasons? **NO = 0 YES = 1**
CODE	**NO. 2**	**NO. 2**	**CODE**	**CODE**	**CODE**

Comments:

V. ACCESS TO HOUSING, FUEL AND HYGIENE

A. HYGIENE

67) Do you have soap present at the place where normally wash their hands? **NO = 0 YES = 1**	**CODE**		**68)** How many flies are in the home? **1.** Many **2.** Some **3.** Very few **4.** None	**CODE**	

B. FUEL

69) What are your primary and secondary sources of cooking fuel?	**1.** Charcoal **2.** Wood	**3.** Petrol **4.** Solar	**5.** Electricity **6.** Other___?	**A) PRIMARY**	
				B) SECONDARY	
70) What are your primary and secondary sources of lighting fuel?	**1.** Candle **2.** Wood	**3.** Petrol **4.** Solar	**5.** Electricity **6.** Other___?	**A) PRIMARY**	
				B) SECONDARY	

C. HOUSING

				CODE
71) What is the main material of the exterior walls of the house?	**1.** Thatch **2.** Wood planks	**3.** Sheet metal **4.** Cinder blocks	**5.** Mud **6.** Other, what?	
72) What material is most of the roof?	**1.** Thatch **2.** Sheet metal	**3.** Tarpaulin **4.** Clay tiles	**5.** Other, what?	
73) What is the predominant material on the floor?	**1.** Sand **2.** Woven mat	**3.** Tarpaulin **4.** Wood planks	**5.** Cement **6.** Other, what? ___	
74) What is the type of stove?	**1.** Charcoal stove **2.** Wood fire	**3.** Solar cooker **4.** Propane gas stove	**5.** Kerosene gas stove **6.** Other, what? ___	
75) What type of toilet has this home?	**1.** Toilet connected to drainage system **2.** Toilet connected to septic tank	**3.** Bowl/bucket **4.** Latrine or cesspool	**5.** No toilet **6.** Other, what? ___	

76) Does this home have a source of electric lighting? **0 = No 1 = Yes**	A.	Generator	
	B.	Solar panel	
	C.	Other, what?	

77) Was your home damaged by the 2009 cyclone?	**0.** Not damaged **1.** Damaged slightly	**2.** Damaged heavily **3.** Destroyed	

78) If you did not need any resources from the mangroves would you still want them to be there? **0 = No 1 = Yes**

79) Why?

Comments:

Comments: