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STATE-AND-TRANSITION MODELING AND ADAPTIVE MANAGEMENT: TOOLS FOR FUTURE CO-DEVELOPMENT OF MADAGASCAR'S NATURAL RESOURCES AND PEOPLE

Patrick Thomas Spencer
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STATE-AND-TRANSITION MODELING AND ADAPTIVE MANAGEMENT: TOOLS FOR
FUTURE CO-DEVELOPMENT OF MADAGASCAR'S NATURAL RESOURCES AND
PEOPLE

By

Patrick Thomas Spencer

A REPORT

Submitted in partial fulfillment of the requirements for the degree of

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In Civil Engineering

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This report has been approved in partial fulfillment of the requirements for the Degree of
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Abstract

Madagascar's terrestrial and aquatic ecosystems have long supported a unique set of ecological communities, many of whom are endemic to the tropical island. Those same ecosystems have been a source of valuable natural resources to some of the poorest people in the world. Nevertheless, with pride, ingenuity and resourcefulness, the Malagasy people of the southwest coast, being of Vezo identity, subsist with low-development fishing techniques aimed at an increasingly threatened host of aquatic seascapes. Mangroves, sea grass bed, and coral reefs of the region are under increased pressure from the general populace for both food provisions and support of economic opportunity. Besides purveyors and extractors, the coastal waters are also subject to a number of natural stressors, including cyclones and invasive, predator species of both flora and fauna. In addition, the aquatic ecosystems of the region are undergoing increased nutrient and sediment runoff due, in part, to Madagascar's heavy reliance on land for agricultural purposes (Scales, 2011). Moreover, its coastal waters, like so many throughout the world, have been proven to be warming at an alarming rate over the past few decades. In recognizing the intimate interconnectedness of the both the social and ecological systems, conservation organizations have invoked a host of complimentary conservation and social development efforts with the dual aim of preserving or restoring the health of both the coastal ecosystems and the people of the region. This paper provides a way of thinking more holistically about the social-ecological system within a resiliency frame of understanding. Secondly, it applies a platform known as state-and-transition modeling to give form to the process. State-and-transition modeling is an iterative investigation into the physical makeup of a system of study as well as the boundaries and influences on that state, and has been used in restorative ecology for more than a decade. Lastly, that model is sited within an adaptive management scheme that provides a structured, cyclical, objective-oriented process for testing stakeholders cognitive understanding of the ecosystem through a pragmatic implementation and monitoring a host of small-scale interventions developed as part of the adaptive management process. Throughout, evidence of the application of the theories and frameworks are offered, with every effort made to retool conservation-minded development practitioners with a comprehensive strategy for addressing the increasingly fragile social-ecological systems of southwest Madagascar. It is offered, in

conclusion, that the seascapes of the region would be an excellent case study worthy of future application of state-and-transition modeling and adaptive management as frameworks for conservation-minded development practitioners whose multiple projects, each with its own objective, have been implemented with a single goal in mind: preserve and protect the state of the supporting environment while providing for the basic needs of the local Malagasy people.

1 Introduction

The vision driving this offertory set of ideas is the perpetual strengthening of sustainable livelihoods and real-world choices that realize the means and opportunities that currently exist for the seafarers of southwest Madagascar. Less abstractly, the efforts contained herein offer a roadmap for development-oriented agencies who strive to obtain the delicate balance between realizing the socio-economic potential in extraction from natural resources and the preservation and strengthening of those very same resources. The research that underpins the vision towards a more sustainable management of coastal resources was born from observational and informal interviews collected and recorded between the period of September 2012 and October 2013 while the author was serving as a Peace Corps Master's International student representing Michigan Technological University within a *fokontany* located within the Morondava commune, a large town situated on the shores of the Mozambique Channel.

1.1 *Development in Madagascar*

As a Master's International Volunteer investigating the value of water resources of the region, the author became privy to a number of domestic and international development organizations who had long-standing presences in the regions of study. In January 2012, the author began to collaborate with a British marine research conservation organization by the name of Blue Ventures. Blue Ventures grassroots-level marine research and conservation efforts began in 2004 in the sleepy coastal village of Andavadoaka, located 200 km north of Toliara. What started as an opportunity to rebuild local fisheries grew into a multifaceted approach to conservation of coastal marine environments while simultaneously nurturing and sustaining local communities along Madagascar's western coastline. Over the next decade, they opened a number of research sites throughout southwest and northern Madagascar, including one located in a seaside village known as Belo-sur-Mer, located just 60km south of Morondava. Over the course of a year, the author befriended and came to assist the efforts of research staff at posts located in four coastal Vezo communities, including Morondava, Toliara, Andavadoaka and Belo-sur-Mer. Each of these four communities has been witness to a host of environmental conservation and development activities, both on behalf of the Malagasy government and international organizations and had working relationships with the staff of Blue Ventures.

1.2 Co-Development of Natural and Human Resource Protection

Worldwide, coastal ecosystems support a rich diversity of plants and animals that form a number of habitats that provide a supporting environment for hosts of natural goods and services. For years, people living in coastal settings have come to realize localized benefits, from capture fish species to the beauty of the natural settings. As people have come to realize the potential of natural resources they have increasingly come to interact with the natural environment, creating a more intertwined social-ecological setting. Unfortunately, the social-ecological systems are not always in harmony; there are a number of influences and drivers that scientists have identified as that directly affect the health of the ecosystem. This has lead ecologists to attempt to qualify and quantify the cause-and-effect feedback that exists between the drivers of ecological change and the environment's response to those potential stressors (Anthony, et al., 2008; Thu & Populus, 2007). However, over the past twenty years, social and physical scientists have come to realize that the ability of ecologists to parse the systems of interactions is limited to the microbial level (Ostrom, 2007). There is a pressing need to understand how the microbial level supports the development of natural resources on a more macro-scale, both to better understand the biological feedback and the effect of human interaction on the ecosystem.

In Madagascar, climatic and human-sourced stressors have been demonstrated to drive hydrological and geomorphic change in both mangroves (Rakotomavo & Fromard, 2010) and coral reefs (McClanahan et al., 2009). As such, conservation organizations such as Blue Ventures have undertaken a number of interventions in order to preserve coastal ecosystems. The new strategy discussed here presents an additional opportunity for development in Madagascar to reach two critical elements of the current intervention strategy of Blue Ventures, namely, the social and ecological interaction central to their integrated development and conservation project. The goal of these interventions are to strengthen the capacity of people living in the region of study and the ensuring the protection and preservation of the region's important natural resources. Adaptive management, and particularly adaptive environmental assessment and monitoring, offers the chance to develop a prescription for guiding coastal ecosystem management strategy for the next decade and beyond. As a strategy for implementing multiple programmatic elements, the strategy is guided by the principles of ecological resiliency – a measure of the adaptability of an ecosystem under stress to maintain its form and

function and thereby absorbing the potential perturbation. Operationally, the application of state-and-transition modeling has been shown to offer a practical approach to engaging all relevant stakeholders at each step of the adaptive management approach to system resiliency and sustainability. State-and-transition models are a process tool that can provide a conceptual map that describes both the current state of any particular system of study, and mechanisms that are thought to either limit or facilitate patterned change (Bestelmeyer et al., 2009). Therefore, it is offered here, in an environmental setting – coastal ecosystems of southwest Madagascar.

2 Madagascar

Madagascar is an island-nation of nearly 22 million people living off the southeastern coast of mainland Africa in the Indian Ocean (INSTAT, 2013). Valued by scientists for its high degree of endemic plant and animal species, the island is oft-cited as one of its most richly unique diverse biological areas in the world (Goodman & Benstead, 2003). Madagascar is the fourth largest island in the world and runs nearly 6000 km north to south and 2000 km east to west at its widest point. A set of three mountain massifs run longitudinally through the center of the island, which combined with the predominantly southwestern trade winds from the Indian Ocean are largely responsible for the various weather pattern found throughout the tropical island. Rainforests can be found along the range's eastern escarpment and lowland areas of the southeast, while the western and southern regions are home to relatively dry, deciduous forests (Tyson, 2000).

Madagascar is one of the poorest countries in the world. The United Nations World Food Programme recently reported that more than 92% of the population currently lives below the international poverty line of \$US 2 per day. The agricultural-based economy has suffered from a lack of industrial machinery, central state support or investments and lack of capital for more than twenty years as the country has seemingly lurched from political crisis to political crisis, only just recently electing a representative executive government (Reuters, 2014). In 2012, the International Food Policy Research Institute placed Madagascar 64th out of 79 countries on its annual Global Hunger Index, and reported that 25% of the Malagasy people were undernourished, and as high as 36% of children under five years of age were found to be underweight (Grebmer et al., 2012). This data underscores the importance of and elusiveness of food security throughout the island. Furthermore, it sheds light on the fact that securing adequate food can be a daily

struggle for a large percentage of Malagasy men and women. Hampered by an antiquated transportation infrastructure that relies almost entirely on commercial and non-commercial trucking, nearly every Malagasy eats food from within the food shed in which they live in for the greatest part of the year. As such, the natural resources unique to each region's environmental setting have come to play a primary role in meeting the provisional needs for health and nutrition. In southwest Madagascar, local Malagasy often turn to the sea for their primary needs.

The growth in population and increasing stress on natural resources can be contextualized by understanding recent economic difficulty facing the local people. The Malagasy economy has stagnated in the nearly three decades since the bankruptcy and failure of the socialist central state throughout the 1980s and early 1990s. The massive debt incurred by the state during the 18-year reign of former President Didier Ratsirika lead to a number of structural adjustments dictated by the International Monetary Fund (IMF). However, the economy and the national currency of the nation, the Ariary, have struggled to realize gains in international markets. Currently, the exchange rate of the Ariary to US dollars stands at nearly 2,300 to 1.

2.1 Area of Study

The study area is a nearly 400 km coastal region of southwestern Madagascar. Specifically, the focus of this research is aimed at the coastal seascapes between the port centers of Morondava, capital of the centrally-located Menabe region, and Toliara, which is capital to region immediately south, Anosy. Morondava itself is home to roughly 85,000 people, while the larger Toliara is home to nearly 250,000 permanent Malagasy residents (INSTAT, 2011). Geographically, the regions of Menabe and Toliara occupy roughly 8% and 12%, respectively, of the roughly 22,000 square kilometers of the island. Between the two port towns rests nearly 200 km of coastline (Figure 1). Southwestern Madagascar has seen a growth in population that has exceeded the national rate, with the population currently doubling every 10-15 years (Le Manach et al., 2012). As a result, the ecosystems that sustain the Malagasy coastal people are under increased pressure to provide for more people. At the same time, and in part because of this population boom, the elimination and degradation of ecosystems in the region has dramatically increased (Rakotomavo & Fromard, 2010).

In the later months of 2012 the author completed a series of informal interviews of local Malagasy, and came to the realization that the vast majority of local Malagasy livelihoods were dependent on the sea. Two studies of the past ten years, Raharison (2010) and Lida (2005) had confirmed that upwards of 80% of the local Vezo have developed livelihood strategies that employ the ocean and its host of goods and services.

2.2 Ecological-Social Systems of Southwest Madagascar

Historically, villages and town of southwestern Madagascar have sustained their need for food through extraction of marine fish and goods. Diligently collected using rather low-development non-commercial means (Cinner et al., 2009), the fish within coastal waters have yielded nutritional and economic benefit to local families for centuries (Le Manach, et al., 2008; Rakotomavo & Fromard, 2010). Malagasy fishermen, found in small villages between the towns of Morondava and Toliara, have historically recognized themselves as both purveyors and protectors of the sea and have come to link not only their livelihoods, but also their social identity, with the ocean itself (Marikandia, 2001). Being reared in such a socialized context, children have come to identify and develop a socialized value found inherently in being a fisherman, and often receive training on means of fishing and seafaring from a very young age (Jones, 2012). The historical roots of the social construct of the coastal people whose historical roots trace back centuries. Locally known as Vezo – a term has come to take on multiple meanings and connotations – it is thought to represent a person's intimate relationship and the ocean and its plentiful resources. The Vezo are relatively poor compared to many of the other ethnic identities found throughout Madagascar (Marikandia, 2001), but the opportunities, both imagined and realized, from the sea have made them the envy of a number of poor agriculturalists and pastoralists.

Ecologically, the coastal landscape of southwestern Madagascar supports a number of marine ecosystems, including four functional types of mangroves, six functional types of reefs along with an abundance of seaweed and fish-rich sea grass beds, that are all found in relative abundance in comparison to the remainder of the island (McClanahan et al., 2009, Gough et al., 2009a). Existing primarily in the intertidal and shallow coastal waters, these ecosystems have been providing a host of goods and services to local purveyors for centuries (Jones, 2012; Marikandia, 2001). Sea squid, sea urchin, octopus, mud crabs, shrimps, sea cucumbers along with a number of large predator fish,

such as shark and snapper, can be found in relative abundance at the local fish market twice a day, coinciding with the ebbing of the high tidal waters (personal observation). With a growing population base becoming increasingly permanently settled in the region (INSTAT, 2012), an emphasis has shifted from agriculture and aquaculture towards tourism as a primary economic driver of the region. In effect, social norms concerning the production value of coastal ecosystems have led to increasing pressure on the capturing of fish and crustaceans from the water and substrates. In turn, some have asked if the use of natural resources in the region can be sustained long-term (Le Manach et al., 2012; Tucker, 2012; Rakotomavo & Fromard, 2010).

Recently, development practitioners and environmental conservationists, both domestic and abroad, have come to witness the potential for degradation and destruction of ecosystems that can occur when additional stress is placed on the various ecosystems. Environmentalists and marine biologists from international organizations like the World Wildlife Fund and Conservation International have sought to preserve and enrich the ecosystems of southwest Madagascar that are home to a number of endemic aquatic biota critical to the unique ecological setting and underpinning of the marine environments. At the same time, development practitioners such as United Nations Food & Agricultural Organization (UN FAO), International Food Policy Research Institute (IFPRI), and the International Fund for Agricultural Development (IFAD) have been searching for sustainable methods of production and alternative livelihoods to supplement nutritional needs and possible economic opportunity. Given the rate of population growth in the region, coupled with a host of ecological indicators that are suggesting a loss of resilience and an increased vulnerability of mangroves and coral reefs, the growing populations of southwestern Madagascar may very well face significant challenges to both nutritional health and economic capacity.

3 Coastal Ecosystems of Southwestern Madagascar

Southwestern Madagascar is rich in both terrestrial and aquatic natural resources that exist within a number of environmental settings that are unique to the island of Madagascar (Scales, 2011; Giri & Muhlhausen, 2008; Casse et al., 2004). Recent research has considered both the nature of use of natural resources while positioning such use within a localized context of value found in both the preservation and exploitation of various natural ecosystems (Stiles, 1991). Most recently, applied

researchers have sought to quantify the effects such exploitation has on the ecological structure that comprises the environments themselves (Vincent et al., 2011).

On land, the state of Madagascar's natural woodland forests have been studied extensively, with much focus being placed upon the social-ecological tension between traditional agricultural practices such as slash-and-burn agriculture and the shrinking forest cover (Elmqvist et al., 2007; Casse et al., 2004). Along the coast, a host of interconnected ecosystems – namely mangroves, sea grass beds, and coral reefs – together comprise the biome identified by Ogden (1988) as a seascape. Often lacking a clear delineation, both in terms of compositional structure and use by local fishermen, seascapes in southwest Madagascar are emblematic of what Moberg and Folke (1999) considered “a complex mosaic of mangroves, sea grass beds and coral reefs interacting in a dynamic fashion, all influenced by terrestrial as well as ocean activities.” Each of these aquatic ecosystems, however, is unique in both its biological structure and organization, and each supports a host of naturally occurring marine resources. To be clear, the structure of the ecosystem can be thought of as the size, composition and expansiveness of the life forms that are used to both qualitatively and quantitatively define each particular ecosystem. When considering mangroves, the structure of the forest is largely defined by the size, composition and diversity of the trees. To coral reefs, the structure is defined here as the composition, size and species diversity of the rigid skeletons of calcium carbonate that interconnect to form colonies of stony coral (Jameson et al., 1995).

3.1 Mangroves

Mangroves are a type of coastal wetland that are characterized by a number of halophytic, or saltwater tolerant, tree species adapted to grow in areas influenced by tides. Mangroves exist within the littoral zone of tropical and subtropical coastlines. The pioneering faunal species that form the initial plant communities fringing coastlines, have the capacity to exhibit growth in both tropical and temperate settings, and have shown to evolve into terrestrial woodlands as silt accumulation builds and the mangrove transitions naturally. As such, mangroves serve a number of ecological functions related to soil entrapment and filtration that provide and maintain beneficial conditions for the buffering sea grass beds and coral reefs.

Two recent studies have explored the relative percent of land cover occupied by mangroves of Madagascar. Both studies utilized geographic information systems to

portray the expansive forests in 10 square meter images that allowed researchers to study the structural composition of the mangroves to within 85% accuracy. Rakotomavo & Fromard (2010) analysis revealed that mangrove cover accounts for between 327,000 and 370,000 ha across the island. Separately, a study of the natural progression of mangrove forest cover from 1975 to 2005 supposed a total land cover of only 279,700 ha after the turn of the century (Giri & Muhihausen, 2008). Spatially, nearly all of the coastal forests are located in the central and south west coast (Rakotomavo & Fromard, 2010), which is the area of interest.

Compositionally, Madagascar is relatively species-poor compared to other Indo-Pacific and African countries with past studies reporting somewhere eight species found on the island (Giri & Muhlhausen, 2008). The forest mangroves are primarily home to eight species found elsewhere in the Indo-Pacific region. *Avicennia marina*, *Xylocarpus granatum*, *Ceriops tagl*, *Rhizophora mucronata*, *Bruguiera gymnorhiza*, and *Sonneratia abla* are the most widely distributed north to south, but localized distributions of *Lumnitzera racemosa* and *Herritiera littoralis* are also found in the western regions (Rakotomavo & Fromard, 2010; Giri & Muhlhausen, 2008; Lebigre, 1984).

Mangroves undergo a progressive development over a natural scale that has both geomorphological drivers occurring over thousands of years, and ecological activity that has shown a shorter life history of anywhere between a few years and a century (Woodroffe, 1992). The natural evolution of mangroves over a particular terrain is driven largely by two factors; namely, tidal conditions and water chemistry factors (Lugo & Snedaker, 1974). Tidal conditions will directly influence the rate of development of the water chemistry, which in turn, influences stem growth, stem reproduction and initial and re-seeding establishment (Farnsworth, 1998). Community dynamics and physiognomic development largely rely on the water chemistry factors, including percentage of dissolved salts, organics and oxygen concentrations (Woodroffe, 1992). Beyond water chemistry and tidal conditions, hydrogeomorphic setting is a third driver of the physiognomy of mangroves (Lugo & Snedaker, 1974; Woodroffe, 1992). Combined, these three hydrogeological conditions are responsible for the development of four primary functional types of mangroves found throughout southwest Madagascar. Functional groupings of mangroves have, historically, been used to by ecologists to describe not only the compositional structure of mangrove faunal species, but takes into consideration the affects that hydrogeological settings have on the natural evolution of

the mangrove itself (Petraitis & Dudgeon, 2003). Functional classifications found in Madagascar's mangroves include 1) overwash islands, 2) fringe mangroves, 3) riverine mangroves, 4) hammock and 5) basin mangroves (Ravaoarinarotshihoarana, 2009). Each of these functional settings stands to represent a different type of mangrove, in term of the physical structure, tidal influence, and type of natural resources found therein. For example, riverine mangroves, in existing along the banks and deltas of tropical rivers, are often subject to a comparatively large amount of sediment buildup flowing from the adjacent river delta. Alternatively, overwash islands are primarily dominated by the influence of waves, and therefore have relatively small amount of sediment buildup, often flushing with large pulse-event waves. The supporting environment in the former will differ greatly from the latter, especially considering the migration of fish and invertebrate species seeking protection. In turn, the environmental setting will become important when considering the interaction between the mangroves and local users or purveyors of the naturally produced goods found therein.

Community development of mangroves can be examined under various timescales, yet there is strong empirical evidence to support the argument that a mangrove is a successional ecosystem with ever-changing physiognomy, largely evidenced by changing bottom, or stratum conditions that are influenced by a host of biological, geomorphological and hydrologic conditions (Lugo, 1980). In instances where established mangrove forests are subject to low tidal energy, the buildup and trapping of sediment around the root structures of pioneering species will slowly lead to the forest shifting continuously towards a terrestrial ecosystem as the mangrove ebbs closer to the ocean edge. Alternatively, with a high level of salinity in the soil the mangrove will gradually shift towards a more hyper saline ecosystem such as a mudflat, especially if tidal influences are low. In instances where tidal influence is high and occurs with regularity, both the buildup of sediment and soil salinity is kept in check as the system flushes. In totality, salinity of both water and soil, climatic and tidal intensity and duration, freshwater availability, and sedimentation are all vital parameters used to describe mangrove-dominated ecosystems. The environmental setting to which the mangroves is subject will strongly influence how the mangrove will be effected by these parameters. What's more, mangroves along Madagascar's southwest coast are also often modified due to their relative ease of accessibility by villagers who live alongside these coastal ecosystems and the socio-economic needs of the region (Ravaoarinarotshihoarana, 2009).

3.2 Coral Reefs

Southwestern Madagascar is home to an expansive coral reef system widely known as one of the largest in the world (Veron & Turak, 2005). The Toliara Reef System runs along the underwater continental shelf that extends north to south and its most prominent feature, a continuous barrier reef dubbed Le Grand Récif, lies only 5 km off the southwest coast of the island. Le Grand Récif is unique in that it stands as one of only five continuous reefs remaining in the world (Jameson et al., 1995). Closer to the shore and surrounding small islands are a number of shoreline fringing reef communities and lagoon patch inland reef communities. The coral ecosystems have historically been considered to have some of the most species-rich reefs in the central and western Indian Ocean (McClanahan et al., 2009). In the final decade of the last century, Madagascar's reef systems were thought to contain over 400 fish species living in and among nearly different 200 coral species (Spalding et al., 2001, Vincent et al., 2011). Recent stressors, both human and climatic, have seen the die-off of nearly 100 fish species (Vincent et al., 2011). In the most southern areas of study villagers have been using a hand-spearing technique for capturing *Octopus Cyanea* that entails men and women walking on and amongst the reef structures as they fish for the invertebrate that hides among the reef structure. Yet, the ecosystem is still highly regarded for its biodiversity, natural protective barrier against coastal storms, as well as its hosting of a number of fish species vital to men, women, and children of the region.

In the same way that mangroves development is shaped by hydrogeological factors, the development of scleractinian, or stony, coral reefs are under the same natural conditions, albeit nearly universally submerged beneath shallow coastal waters and with very different biological makeup. Coral reefs of the shallow waters of Madagascar are generally small, stony corals of the *Acropora* genus whose coralline polyps become interconnected to form what is often referred to as "plate" colonies in shallow, light-penetrating waters (Gough et al., 2009). The makeup of coral communities in the southwest regions, especially around the villages of Andavadoaka, is composed of seaward fringing and barrier reefs resting upon hardened rock or calcareous alga, and sheltered fringing and lagoon patch reefs whose polyps have been evidenced as forming on loose unconsolidated coral rubble (Spalding et al., 2001). These coral communities support benthic communities that provide food for the polyps and herbivorous fishes found living within the aquatic ecosystem (Vincent et al., 2011). Overall, coral cover in

the region has been estimated at less than 20 percent, with colonies increasingly under systemic pressure from competing schemes, primarily algae-dominated communities (Gough et al., 2009).

3.3 *Links between Mangroves and Coral Reefs*

Ecologically, mangroves and coral reefs are linked through a series of environmental functions that seek to preserve the health and natural ecological processes that support the structure of each. These are, in part, the functions of the ecosystem, or rather, what the ecosystem does in serving a benefit or purpose. Specifically, each helps to provide a buffer against natural disturbances that are found within bordering terrestrial and open-ocean ecosystems. Mangroves, given the makeup of their tree species, and the particulars of their root structure, serve two primary functions that are of benefit to coral reefs. Mangrove trees help to prevent erosion of the intertidal zone by capturing sediment runoff from rivers and land. Similarly, they also absorb and trap nutrients that would otherwise enter the ocean and provide food for the growth of algae and aquatic plants. Left uncontrolled, algae and aquatic plants could come to blanket the coral polyps and kill not only the reef structure, but lead to the destruction of nesting and protective environments for a number of fish species and other aquatic organisms. The development of mangroves, particularly lagoon-type forests, also interrupt the flow of freshwater discharge into the ocean, which has an effect on balance of nutrient levels in fringing coral and near-shore coral reefs. Lastly, mangroves themselves are nesting areas for a number of saltwater fish and crustaceans that, depending on the time of year and gestational period of the fish, enter coral reefs and provide supporting and provisional services for the species found in and among reefs (Moberg & Folke, 1999).

Coral reefs, similarly, provide a natural buffer against the potentially destructive energy that is found in the open water. The intricate and hardy structure of the reef systems have been shown to dissipate wave and current action (Mazda et al., 1995). This was evident in a set of explorative dives undertaken by the author alongside scientists of Blue Ventures on the fringing coral reefs lining the bays of the village of Andavadoaka in August 2013 after the devastating effects of inland flooding following a February cyclone. The sparing of the immediate coastline demonstrated how the coral reefs absorbed and dissipated much of the wave action that had formed in the Mozambique Channel. In addition to serving as a natural barrier, the fish and invertebrates larvae found in coral

reefs have been shown by ecologists to migrate towards shallower mangroves and sea grass beds for protection during the period of maturity (Ogden, 1988).

4 Benefits of Coastal Ecosystems in Madagascar

Given the rich biodiversity and high productivity of mangroves and coral reefs, the collective coastal ecosystems have been witness to the provisioning of goods and services to both local resource users and non-users alike. Productive benefits are defined here as primary goods that are borne of mangroves, sea grass beds or coral reefs. These primary benefits require very little or no external or additional input in order to yield a marginal increase to the purveyor's welfare. Examples of these are capture fish species, such as crabs or octopus, or straight tree trunks to be used as sailing masts. Secondary goods, on the other hand, require additional input, sourced in form of skilled or unskilled labor or the addition of other goods, or otherwise may not necessarily provide a marginal increase to the user's welfare. These can include the production of furniture, charcoal and even boats. Throughout southwestern Madagascar, local Vezo fishermen often utilize the mangrove trees to make boats of various sizes and dimensions.



Figure 2: Secondary Goods of Mangroves in Southwest Madagascar (photos by the author)

Furthermore, both users and non-users may find an inherent value in the order and structure of the seascape. For the purposes of this primary exploration into the possible application of adaptive management, focus will be given to the primary goods – seafood – that are borne from the biological and ecological structures and processes that underpin and are generally agreed as defining mangroves, sea grass beds and coral reefs. Nevertheless, the secondary benefits of seascapes of southwestern Madagascar are too important to disregard in their entirety; thus, an overview of these benefits is also addressed.

4.1 Primary Goods of Seascapes

Mangroves

Mangroves in southwest Madagascar are home to a number of fish species that utilize the nutrient-rich stratum conditions for both reproductive and nutritional purposes. The limited research completed on species assemblages in southwestern Malagasy mangroves has shown as many as 60 fish species live within the intertidal zone of the regions diurnally flooded mangroves. The work of Laroche and colleagues (1997) stood as the most comprehensive undertaking on mangrove composition in the region, identifying 60 species of fish within the mangroves around Toliara, with four fish families, Gerreidae, Teraponidae, Carangidea and Sparidae, representing more than two-thirds of the species abundance. Towards the center of the western coast, as overwash and fringing mangroves tend to give way to more inland riverine mangroves, the relative abundance of terrestrially adaptable sea creatures are used by local users. Specifically around the region of Belo-sur-Mer, mud flats are host to, amongst other species, the *Scylla serrate*, which has proven to be the most prevalent crustacean used by local people (Ravaoarinarotshihoarana, 2009).



Figure 3: Mud Crab Collection in Lovobe, Madagascar (photos by the author and Jérémie Bossert, Blue Ventures)

Indeed, the importance of the mud crab to the functioning of the social-ecological ecosystem is such that its relative abundance has been used as a proxy for the productive property of mangroves in southwest Madagascar (Ibid, p. 4). The crustacean

has come to take to the muddy flats absent of much forest cover, which would trap the runoff of sediment from land. During low tides as the flats are exposed to the air, coastal researchers have taken to counting the holes that the *Scylla serrate* burrow into for protection during their gestational and initial growth period.

Coral Reefs

Worldwide, nearly 9% of all fish consumed by humans have come from the species that live in and among coral reefs (Smith, 1978). Research supported by the World Wildlife Fund and International Coral Reef Action Network reported that seafood from coral reefs provided US\$5.7 billion in annual net benefits worldwide at the turn of the 21st century (Cesar et al., 2003). Reefs have been found to generate various seafood products, including fish, sea cucumbers, seaweed, mussels and various crustaceans, such as crabs (Moberg & Folke, 1999). Madagascar's coral reefs are home to a variety of renewable resource goods that are found in reef structures throughout the south and West Indian Ocean. *Octopus Cyanea*, which seek sheltered protection and nesting area within and around the shoreline fringing reefs, are highly sought by fishermen due to their higher market value in the region. In recent years, increasing pressure has been placed on Madagascar's coral reefs as local Vezo fishermen have moved from relying on catches for subsistence to more market-driven enterprises (Vincent, et al., 2011). The *Octopus Cyanea* comprises upwards of 70% of current market value of marine resources in the region (Bendow & Harris, 2011). Therefore, local Vezo fishermen strategies for capture of the sea creatures has turned to more mass-catch strategies as they come to rely upon fishing as their main and only source of income (Jones, 2012). In turn, recent sampling counts in and around the Andavadoaka area have suggested that counts of the cephalopod have had a marked decrease over the past decade. This is occurring in spite of the octopus' relatively short gestation period, as compared to other marine life.

4.2 Secondary Natural Products of Seascapes

Mangroves

The community assemblage of both fish and forest have been proven to be a natural resource for users who have realized a number of primary goods outside just the *Scylla serrate* or mud crabs. The mangroves in developing countries have been used by locals for goods as varied as wooden materials for construction to fish poison and dye for

tanning leather (Rönnback, 1999). Specifically, Warren-Rhodes and colleagues (2011) sought to glean village-level economic value of mangroves in the Solomon Islands, and even took to ranking the host of goods and services discovered in their research. Food, in the form of propagule plants, fish, birds and eggs, shrimps, mollusks, honey, seaweed, tea, vinegar, and other consumables accounted for a single categorical good sourced by mangroves on the islands. Additional categories included fuel (both firewood and charcoal), construction materials, fishing materials, tools, household items and five uncategorized goods.

Table 1: Mangrove Goods of the Solomon Islands (data from Warren-Rhodes et al., 2011)

Ecosystem Good	Primary or Secondary Good	Ecosystem Good	Primary or Secondary Good
Fish		Fishing Materials	
Propagules	Primary	Fishing floats	Secondary
Fish	Primary	Fish poison	Secondary
Birds & eggs	Primary	Tools	
Shrimps	Primary	Stakes & Fence	Primary
Mollusks	Primary	Coconut husk (floor cleaning)	Primary
Honey	Primary	Digging instruments	Primary
Seaweed	Primary	Household Items	
Tea, vinegar & other	Secondary	Furniture	Secondary
Fuel		Mortar and pestle	Secondary
Charcoal	Secondary	Dye for nets & cloths	Secondary
Firewood	Primary	Glue & wax	Secondary
Construction Materials		Tannin for nets	Secondary
Poles & beams	Primary	Other Goods	
Boats	Secondary	Traditional medicine	Secondary
Wharfs	Secondary	Animal pens	Secondary
Fishing Materials		Fertilizers	Primary
Traps & fish shelters	Secondary	Handicrafts	Secondary
Spears & nets	Primary	Kaston art	Secondary

The total number of goods identified by local users totaled 30 and is demonstrated in Table 1. Through personal observations, it has been confirmed that nearly each of the goods discovered in the Solomon Islands were replicated in southwestern Madagascar. In 2007, Rönnback and colleagues undertook a similar study on the coastal waters of Tanzania, with similar results.

Coral Reefs

Research has shown that coral reefs often yield a host of primary goods derived directly from the coral reef ecosystem. The presence of the reefs also serve a set of biological, informational and social services that are realized through either direct use or even non-use (Moberg & Folke, 1999). Estimates from 2003 found that the total net present value of benefits borne from coral reefs for the next fifty years (discounted 3%) to be more than \$US 797 billion (Cesar et al., 2003), and annual net benefit streams totaling more than \$US 29.8 billion across the globe. Placed into context, the 2012 gross domestic product for the entire island-nation of Madagascar was estimated to be a mere \$US 21 billion (CIA Factbook, 2013). Localized mining of reefs towards the production primary goods, such as lime and cement, has historically been considered a primary good of coral reefs (Moberg & Folke, 1999), but due to localized theories of value (Tucker, 2012) and lack of high-development equipment (Gough et al., 2009a), they are framed as a secondary good when considering the context of southwest Madagascar. On the other hand, neighboring island-nations in the Indian Ocean, such as Maldives, have considered coral blocks, rubble and sand to be a primary building material (Cesar, 1996).

4.3 Natural Services of Coastal Ecosystems

Natural Protection

The recent historic geophysical characteristics and compositional makeup of the three primarily intertwined types of coastal ecosystems in southwestern Madagascar have given witness to the fact that mangroves, coral reefs and sea grass beds often serve as natural barriers from otherwise detrimental natural disasters. Cyclones forming in the southern Indian Ocean strike both the western and eastern coasts of Madagascar regularly during the rainy season, and often these powerful storms are of erosive and destructible nature. The density of forest cover in healthy coastal mangroves serves as a breaking barrier to the energy of tidal waters during high pulse tides, particularly during

storms occurring during the first few months of the calendar year (Kathiresan & Rajendran, 2005). Specifically, it has been proven that a six-year old mangrove forest 1.5km wide has the capacity to reduce and dissipate the energy of a 1m high wave in open water and a 0.5m wave that strikes shallower coastal areas. (Mazda et al., 1997). In February 2013 nearly the entirety of the southwestern coast was hit by a strong cyclone that moved first north up the Mozambique Channel before reversing direction off the coast of Morondava and turning back south. The destruction caused when the cyclone made landfall was extensive, primarily due to high winds and heavy rains. Local marine forecasters in Andavadoaka worried that the tidal action would be greatly exacerbated by the storm, causing additional flooding and destruction. However, the waters in the coves and shorelines of Andavadoaka did not see extensive seawater flooding (S. Peabody, personal communications). A research trip measuring coral cover undertaken in August 2013 demonstrated that the fringing coral reefs surrounding a number of particularly vulnerable areas were extensively damaged from the storm, but most likely acted to dissipate wave energy that was caused by the cyclone.

Carbon Sequestration

Both coral reefs and mangrove forests are vast regions of carbon sinks, given both their structure and biological processes. Both mangroves and algal species situated in the intertidal waters remove atmospheric carbon dioxide through photosynthesis, trapping the carbon at the molecular level. As foliage falls to the water and dies, carbon also becomes trapped in sediment at the bottom of the mangrove. As the sediment builds up, the absence of dissolved oxygen provides an environment in which carbon can continue to buildup in the substrate. Therefore, the carbon stock, upon settling with decaying fish and plant species, is prevented from oxidizing and reentering the subsurface waters. In mangroves, the stocks and roots of the trees work to trap and build up sediment, thereby supporting the trapping of settling carbon. This supporting mechanism is secondary, of course, to the carbon that is taken up by the leaves of the trees during photosynthesis. Recent research on the rate and limits to carbon sequestration of carbon in mangroves have concluded that, on average, 1.5 metric tons of carbon is stored per hectare of tropical mangrove each year. In total, 18.4 Terra grams of carbon is stored by mangroves worldwide, every year (Patil et al., 2012). What's more, mangrove ecological conditions have demonstrated that the storage capacity of both the flora and soils of

mangroves are nearly five times greater than the storage capacity found in terrestrial forests (Donato et al., 2011).

4.4 Environmental Influences

Coral reefs are susceptible to both systemic and one-time perturbations. The global decline of coral reefs over the last 100 years has shown to be negatively correlated to increasing surface seawater temperatures (Maina et al., 2008). Given the unique setting of coral reefs in southwest Madagascar with regards to climate, ocean and geography, coral reefs are subject to increased exposure from stressors while the composition has, historically, shown limited adaptability (Cinner et al., 2012). Research on temperature conditions in the southern Indian Ocean off the coast of Madagascar lead McClanahan and colleagues (2009) to suppose a more direct causal link of rising seawater temperatures and a threshold beyond which the environment can no longer support coral communities. This threat holds especially true for the waters off the coast of southwest Madagascar. Empirically collected data of sub-Saharan regional coastal waters has shown an average temperature rise of approximately 0.010°C per year (McClanahan et al., 2007), while temperature rise in southwest Madagascar waters have shown evidence of rising at a rate of 0.016°C per year (McClanahan et al., 2009). At the same time, research by Blue Ventures marine scientists has shown that matted and fleshy algal cover, which competes with reproducing scleractinian coral species for binding sites on the hard, rocky substrate, currently occupies between 5 and 50 percent of the reef structure; these levels are significantly higher than historical averages (Gough et al., 2009).

Mangroves, existing in the intertidal zone, face a number of risks from their own natural environment, competing marine and terrestrial flora and fauna, as well as pulse and longer-term climatic events. The deforestation of mangroves is caused by both the need of local users to extract goods from the forest and the non-extractive natural stressors facing mangroves. Geomorphologic condition in the southern Mozambique Channel are subject to a relatively wide tidal range, which means that topographic and geographic setting of inland environments and coastal ecosystems in the region have had to adapt to a number of changing parameters. Climatic and oceanographic changes are not only having an effect on Madagascar's mangroves. It is estimated that worldwide mangrove cover has been decreasing at a rate of between 1 and 2 % annually. Furthermore,

mangrove forests are now endangered or nearly extinct in 26 of the 120 countries where they are found (Duke et al., 2007).

5 Co-existence of Social & Ecological Systems

The people of southwest Madagascar have settled among the mangroves, coastal reefs and sea grass beds in order to utilize the natural goods and services that the seascapes provide. However, the topographical setting and relative proximity to semi-permanent and permanent coastal communities have required that riparian, coastal and near-shore aquatic ecosystems of southwestern Madagascar adapt to the additional stressors that human use introduces to their processes and controls. Although the studied seascapes appear to be biologically rich and diverse, this is somewhat attributable to the low technological methods that Malagasy use, especially in the capturing of fish, crustaceans and invertebrates. At the same time the mangroves and coral reefs are facing threats from climatic and other anthropogenic forces unrelated to fishing.

5.1 *Extractive Influences on Composition*

Extractive resource use has shown a pattern of increase in not only native fish and marine stocks, but research has also shown that the native vegetation itself is often largely impacted by human activities. The reclamation of both mangrove trees and mangrove fauna has been undertaken for both extractive and non-extractive uses (Ellison & Farnsworth, 1996; Warren-Rhodes et al., 2011). Some of the species of trees found most common to mangrove forests in Madagascar have been extracted for a host of direct uses, including construction and fuel sources. Lebigre (1984) identified that the straight trunk characteristics of the *B. gymnorhiza* and *Rh. mucronata*, common in Madagascar, are typically used as poles for construction and as supports for boats, given their 5m and greater height. The density of the *A. marina* species makes the tree prone to extraction and collection for firewood. The extraction for logging purposes represents 16% of the mangrove forest loss in the past three decades (Giri & Muhlhausen, 2008). Logging, however, represents the primary extraction towards nearly two-dozen goods that researchers have ascertained local users realize from mangroves in both Tanzania and the Solomon Islands (Warren-Rhodes et al, 2012; Ronnback, 2007).



Figure 4: Evidence of Logging of Mangroves for Materials of Construction (photos courtesy of Raegan Spencer)

The deforestation of mangrove forests is not only caused by local craftsmen requiring wood, but is also driven in large part by the ever-present need for food. Recent studies from Madagascar have shown that conversion to agriculture and aquaculture are responsible for 35% and 3% of the destruction of mangroves from 1975 to 2005 (Giri & Muhlhausen, 2008). Agriculture, being the second largest compositional sector of Madagascar's gross national product (CIA World Factbook, 2013) undoubtedly represents a vital means of sustenance for many rural Malagasy people. The means of agricultural and pastoral production throughout the island has, controversially, relied upon the use of what is known as "slash-and-burn" agriculture. Slash-and-burn agriculture is an agricultural technique often employed in low-technology nations such as Madagascar. The technique employs the cutting and burning of terrestrial forest, often at the edge of existing agricultural land, in order to both clear the area of forest cover and provide for the growth of young saplings, which will after a few years will themselves be burned in order to produce charcoal. The second burning of the remaining forest cover provides a carbon-laden ground cover for natural grasses to grow. This now grassland will either be tilled for agricultural purposes or grazed upon by the many rural pastoralists (Raharimalala et al., 2010). In addition to the loss of forest cover and the benefits of terrestrial woodlands, the effects of slash-and-burn agriculture and deforestation in general, can have altering effects on bordering mangrove forests. This can include increased sediment and nutrient runoff to aquatic ecosystems.

5.2 *Local Management Influences on Ecosystems*

Research on coastal seascapes, including mangroves, coral reefs and sea grass beds, has come to the conclusion that human impact on coastal ecosystems are having a dramatic impact on the ecological functioning of these ecosystems (Bellwood et al., 2004; Cinner et al., 2009; Spalding et al., 2001; Warren-Rhodes et al., 2011).

Madagascar, whose relative development surrounding coastal ecosystems is historically low for the African region (McClanahan et al., 2009), is undergoing a population boom, with an annual growth rate north of 2.3% for the southwest region (INSTAT, 2012).

Given the historical and current reliance on natural resources, both terrestrial and aquatic, a number of attempts have been made to qualify and quantify the anthropocentric impact on mangroves (Ellison & Farnsworth, 1996; Alongi, 2002; Rakotomavo & Fromard, 2001) and platform and fringing coral reefs (Vincent et al., 2011; Hughes et al., 2003) over the last thirty years.

Two factors are influencing the extractive pressures facing seascapes in southwestern Madagascar. Given the siting of semi-permanent and permanent villages around resource stocks, it's not surprising that the opportunities found within coastal ecosystems attract not only localized native, but many Malagasy emigrants, particularly during the cool, dry months of the year. Secondly, the Malagasy local and regional governments lack both the physical resources and respected authority and legitimacy required to license and patrol the catches of non-commercial fishermen (Le Manach et al., 20011). Therefore, there is additional anthropocentric pressure that these social-ecological systems face, while at the same time, evidence of similar situations in other African countries has shown the level of settlement and community development to be negatively correlated to the health of the ecosystem (Cinner et al., 2009).

One such community seeing a population growth and development is the seaside village of Lovobe, which is a permanent village located just six kilometers south of Morondava. In May 2013, the author accompanied Blue Ventures project management and marine science team to the opening of a "no take" area (NTA) within a riverside mangrove situated on the northern edge of the village. Blue Ventures staff had negotiated with village leaders to agree to a three-month closure of an important mangrove area situated along the mouth of Betania River, a naturally-flowing river that originates inland at the base of one of Madagascar's massifs. Returning to oversee the returns on *Scylla serrate* crab catch stocks, the research team found that certain village fishermen, in response to

edict banning extraction from fishing grounds, had manually trenched and widened a previously low-flow rivulet that split from the Betania River approximately 1.4 km upstream of the closure site in order to construct a makeshift fish dam in order to preserve their catches. Their efforts not only undermined the temporary protective area but also resulted in the reorganization of the ecosystem itself.



Figure 5: Rivulet & Manmade Dam near Lovobe, Menabe Region, Madagascar (photos by the author)

Evidence has shown that the increasing human dependence on fish stocks for both primary sustenance as well as economic gain has resulted in additional pressures upon the composition of coral reefs in the region, as well. In recent years, as the worldwide consumption of seafood has steadily increased from 114 million metric tons in 2006 to more than 138 metric tons in 2011 (FAO, 2012), local fishermen in southwest Madagascar have found economic opportunity in selling their catches of octopus and squid, particularly *Octopus Cyanea*, to international fish distributors such as Copfrito and Murex (Humber et al., 2006). Lacking sophisticated equipment (Gough et al., 2009), Vezo fishermen continue to exploit near-shore fringing reefs rather than exploring further offshore fishing grounds (Jones, 2012). Furthermore, traditional low-development methods of fishing for both octopus and squid involved men breath-diving and using a spear to “tickle” the cephalopod and extracting it from under rocky areas (Gough et al., 2009). Evidence has shown that as the pressure on fishermen to produce higher yields has increased, fishermen have taken to more destructive techniques that include the setting of floating nets and increasingly seeking the creatures by walking atop reef

structures during low-tides (Jones, 2011; Cripps, 2009). Evidence collected of artisanal methods of fishing in the South Pacific have found that the extractive technique and frequency of fishing were directly affecting the underlying processes and undermining the entire structure of the ecosystem, putting it in a very threatened states (Bellwood et al., 2003).

5.3 *National Management Influence on Ecosystems*

Over the last decade, the applied research teams with Blue Ventures have adopted a series of strategies that examines one potential intervention over a period ranging from three months to five years, providing monitoring and support to resource users, and have changed strategy only if the favored intervention fails to meet the goals of both conservation teams and ecosystem users. This “trial and error” style of management has been seen to be both costly to implement and monitor and has led to a series of unintended economic hardships for resource users and unrealized goals on the part of the decision makers or village councils (Keith et al., 2010; Duncan & Wintle, 2008). Perhaps most notably, from 2009 to 2012 Blue Ventures elected to address both conservation of natural resources and sustainability of livelihoods through the establishment of a robust protection scheme for a marine extension to Kirindy Mitea National Park. Originally established in 1997 during first phase of the Malagasy government’s National Environmental Plan (PE1), the national park is located 70 km south of Morondava just inland of the coastal village of Belo-sur-Mer (Atona, 2004). Stretching over 72,000 hectares, the nationally recognized preservation area is today home to 11 species of mammals (10 of which are endemic to the area), 47 total species of birds (33 species are endemic), and 23 species of reptiles, all of which are endemic to the park area (ANGAP, 2002). Starting in 2009, Blue Ventures opened a research office in the middle of Belo-sur-Mer village. In short time, they brought together a host of local and national actors, including village leaders from Belo-sur-Mer and surrounding coastal villages and *fokontany*, regional administrators and public consultants, Madagascar National Parks, and a proposed MPA manager to help locals gain awareness of the resource stakes that had come to be regarded as at-risk. Natural resources, including fish, had been found to be under increased pressures due to the boost in tourism to the area, as well as the emigration of additional Malagasy seeking employment either in the park or in one of the suddenly burgeoning surrounding villages (S. Peabody, personal communication). Over the next three years, Blue Ventures led these actors in proposing

to establish a marine protected area extension of Kirindy-Mitea to the Association Nationale pour la Gestion des Aires Protégées (ANGAP), going so far as finalize a MPA management and zoning plan, developing enforcement procedures for rules and regulations, installing infrastructural support and even establishing a “comité de vigilance”, or a patrol and enforcement committee (Jones, 2012).

In 2012, the goals of the proposed MPA extension of the Kirindy-Mitea were yet to be realized, with evidence gleaned from informal interviews of the political and bureaucratic decision makers suggesting that the imposition of a large-scale external conservation rules was undermining the more traditional management of the coastal ecosystems (Bossert, personal communications). Furthermore, the scope of the objective of the MPA involved a substantial policy change on the behalf of a number of political actors who had previously never approached such inter-village policies, and who could not agree on either the urgency of action or the optimum set of strategies for enforcement. Such sentiments had been unearthed in a similar study undertaken by Jones, Andriamarovololona and Hockley (2008), which more anthropologically investigated the roles of social norms and taboos in the protection of wild mammalian species around Ranomafana National Park in eastern Madagascar.

In turn, Blue Ventures shifted focus from large-scale conservation activities to supporting more localized series of actors who, in being readdressed, were encouraged to consider more low-risk (politically speaking) decisions regarding the conservation of the goods and services found within their area of jurisdictional oversight. Starting in 2012, village-level fishing management structures started to take hold in a number of villages and *fokontany*, including the village of Lovobe. In conjunction with local elders and traditional management structures, the research team started monitoring temporary closures of targeted mangrove, sea grass bed and reef fishing grounds, with the aim of allowing for resources to be replenished. In leveraging the capacity of existing power structures and largely abandoning the process of their own research interests, the Blue Ventures team has gained traction in monitoring coastal ecosystems in nearly a dozen villages that otherwise would have made up the MPA management structure. In 2013, Blue Ventures, in continuing to dissuade scientific self-interest (Walters, 1997), realized an obvious gap in their linkages between ecosystem function and social health. Therefore, the organization began integrating health measures and opportunities as part of a comprehensive population-health-environment (PHE) initiative and, in July 2014, began

providing the training, materials and support of a nurse in the small village of Lovobe, home to nearly 1,000 semi-nomadic Vezo fishermen and their families.

Indeed, the very motto of Blue Ventures, “research through discovery” speaks to the dedication of the entire organization in preventing what Walters (1997) described as “self-interest in research and management objectives”.

6 Development of Ecosystem Preservation Strategies

Given that seascapes of southwestern Madagascar are driven by a number of internal and external processes, the criteria for addressing the conservation of the natural resources and healthy structure of the ecosystems must convey both the natural function of the seascape and the needs of the people living amongst the ecosystem. As evidenced through personal observations and conversations with villagers in Andavadoaka, Belo-sur-Mer and Morondava, a number of realized goods and services were observed, including capture fish species, firewood and construction materials. However, the Vezo people also hold to the inherent or natural benefits of mangroves and coral reefs, realizing such benefits as natural protection and biodiversity (Marikandia, 2001). In a study of mangrove forests in the Solomon Islands, the supporting of the fish habitat was ranked as the second most important service provided by the ecosystem (Warren-Rhodes et al., 2011). More generally, primary products were only one of five primary goods and services discovered by researchers to hold nearly universal appeal. Natural protection, water quality, diversity of the biome, and toilet function were all acknowledged by a majority of the local resource users. These non-market services demonstrate the complexity of the social-ecological system, and the ever-present needs of the people for healthy livelihoods. The question, then, is how does one place a value on such services?

6.1 *Public or Universal Goods & Services*

Beyond the local resource users, there is increasing acknowledgement that the goods and services afforded by health ecosystems also directly effects the quality of life of those who live downstream of such resources. As the world is increasingly linked both economically and climatically, there is growing evidence that changes at one particular spatial scale can and do have an effect at scales both smaller and larger than the focus of study. In thinking more globally, Blue Ventures has sought to capitalize on a number

of non-market services that have increasingly gained traction in an emerging development paradigm called Payment for Ecosystem Services (PES).

In being labeled as a uniquely rich biodiversity hotspot by Mittermeier, Myers and Mittermeier (2000), the island of Madagascar has seen an influx of conservation organizations arriving with the aim of protecting and preserving the plant and animal life that make up the island's terrestrial and aquatic ecosystems. Within a few years, a number of critical analyses argued that the classification of an ecosystem as a hotspot did not, in and of itself, offer any practical solutions to protecting the ecosystem services that were used to partially define the term (Kareiva & Marvier, 2003). In response, a number of emergent strategies have been developed and tested by organizations such as World Wildlife Fund and Conservation International to determine ways to protect the host of services afforded by health ecosystems. These integrated conservation and development projects (IDCP) have been developed to hold benefits strong for both local resource users and stakeholders who reap benefit from the natural resources. Supported by groups such as the United States Agency for International Development (USAID) and the United Nations Collaborative Fund on Reducing Emissions from Deforestation and Forest Degradation in Development Countries (UN-REDD), these IDCP projects have increasingly been used to support human development through local conservation measures. One of the central questions to IDCP projects is that of what resources are of most importance and how does one measure such resources. Increasingly, there is evidence that payments for ecosystem services represent one such strategy to address both issues.

6.1 Current Monitoring Measures

Of the host of IDCP strategies that conservation organizations such as Blue Ventures perform, there are two that have the potential for the greatest impact on the conservation of ecosystem resources. The longest-standing strategy that Blue Ventures has supported for more than 10 years is the establishment and monitoring of locally-managed marine preservation areas (LMMA). The LMMAs are enforced and monitored to better understand the effect of restricting access, and thereby limiting the anthropogenic stressors, to the social-ecological seascapes in southwest Madagascar. The vision and aim of the endeavor is straight-forward; by restricting access to fishing rights in particularly overfished areas, the expectation is that fish and invertebrates will naturally replenish, given enough time. This decision is often made amongst mangroves

and coral reefs that have historically produced sufficient catches, but whose numbers have recently fallen short of expected quotas. Therefore, the monitoring is often limited to the primary goods that are extracted from mangroves, sea grass beds and coral reefs. In establishing a number of local marine preservation areas in and around Belo-sur-Mer, the primary aim of the strategy have been to restore fish species, particularly mud crabs. In fact, there were limited or no restrictions placed by the local CBNRM association on the removal of trees from the fringing forest along a number of the rivers. The monitoring that was to take place was of fishermen entering and fishing the areas during the closure period. Without much attention being paid to particular drivers of ecosystem change, the results have been mixed. Scientists with Blue Ventures have posited that the return of fish is no longer a presupposed conclusion; given the changes that are occurring to the structure of the mangroves, it is no longer imagined that certain seascapes will provide the same nature of habitat for fish and invertebrates (G. Cripps, personal communication). The second strategy being developed to address the potential destructive nature of human activity in coastal ecosystems is that of payments for ecosystem services.

6.2 Payment for Ecosystem Services

Payments for ecosystem services (PES) represent a tool that can be used to measure the value of a particular ecosystem of study. It is based on the premise that any linked social-ecological system has a measurable benefit to the local resource users. Warren-Rhodes and colleagues (2011), and Rönnebeck, Crona, and Ingwall (2007) elicited the direct benefits of mangroves in the Solomon Islands and Kenya, respectively. However, ecological economists have supposed that these represent but a fraction of the total provisioning and supporting services that are inherently found within coastal ecosystems (Tacconi, 2012; Farley & Costanza, 2010). Indeed, there are a number of non-market goods and services that are sourced, in part, by mangroves and coral reefs; the regulating of water quality, provisioning of carbon sequestration and servicing of biodiversity represent three benefits borne from mangroves and realized directly by downstream users and others.

Water quality, carbon storage and biodiversity are ecosystem services that are relevant to the entirety of the world's population, as each addresses the problem of climate change that is currently affecting people far-removed from the seascapes of southwest Madagascar. However, the sustainability of these valuable services has, until recently,

lacked an incentivized vehicle through which remote populations may influence the management of these natural assets. The development of PES is an opportunity to connect local resource users and managers with downstream users who value the conservation or protection of these services. Realizing that the local resource users may find an immediate benefit to not conserve these services in place, non-locals can offer a payment to users in order to avoid the destruction or degradation of the ecosystem that supports these services.

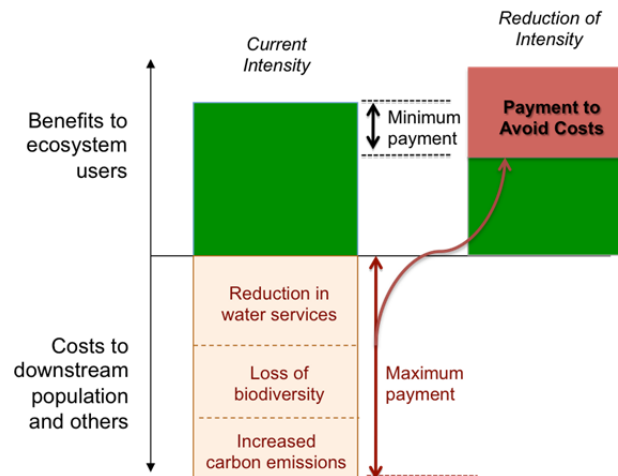


Figure 6: Payment for Ecosystem Services (adapted from Pagiola et al., 2008)

The use of PES as an IDCP tool for preserving Madagascar's natural resources has been initiated in just the past few months. In February 2014 the Wildlife Conservation Society announced that it facilitated the sale of carbon credits from the Government of Madagascar to Microsoft through the CarbonNeutral Company. The premise of this market-based transaction centered on the carbon sequestering benefits that non-locals realized existed within the Makira National Park, a sprawling rainforest found in southeastern Madagascar. Makira National Forest is managed by a community-based natural resource management (CBNRM) team established during the first phase of the national environment board, *Office National de l'Environnement*, national environmental action plan (NEAP). The PES arrangement organized by Wildlife Conservation Society closely followed the definition put forth by Wunder (2005); that is, the sale of carbon credits was:

1. a voluntary transaction
2. a well-defined environmental service (carbon sequestration)
3. 'purchased' by at least one service buyer (Microsoft Corporation)

4. from at least one service provider (CBNRM team)
5. provided the service provider secures service provision

In this case, the environmental service being purchased was carbon sequestration, which necessitates a healthy ecosystem that can continue to sustain the service of interest. In the case of the Makira National Forest, the managing authority has historically demonstrated legitimacy from both the Government and Madagascar and local resource users. The CBNRM is seen as being able to set management objectives that will continue to perpetuate a healthy ecosystem state that is demonstrative of the ability to capture carbon through photosynthesis. The measurability of this and other environmental services and the ability of coastal ecosystems to support these valuable services is the basis for the management framework offered below.

6.3 Need for Tools of Measure

Blue Ventures has recently sought to capitalize on the emergence of carbon swapping markets by introducing the PES framework to its IDCP portfolio of conservation and development strategies. The effort to conserve the natural resources of Madagascar's mangroves and coral reefs are complicated by the social needs of the people and the benefits that they have realized from coastal seascapes for decades. Despite their low technology, there is ample evidence throughout the coast that mangrove and coral reefs are being overly exploited for not only their fish and invertebrates, but for their trees as well. What's more, ecological evidence points to the fact that both mangroves and coral reefs undergo a natural successional evolution wherein the ecological and biological processes evolve and shift over the period of years. Given this state of flux in both natural succession and dramatic anthropogenic change, there is a need to understand whether or not the ecosystem scale of interest:

1. Currently supports the environmental services that are of value to both local and non-local users; is the ecosystem perpetually existing in a 'healthy' state
2. How the environmental setting may be altered and what processes can be targeted to address the need to return the ecosystem to a 'healthy' state

This understanding requires that the local users and managers develop a strategy in which they can measure a number of characteristics of the ecosystem that are driving the classification of the coastal ecosystem. The aim of most intervention is towards the perpetuating of an ecosystem that can support a number of goods and services; in

southwestern Madagascar, the primary goods have a value to local users while secondary services have been evidences as valuable to people all over the world. Therefore, the question is how to map a path towards a healthily dynamic ecosystem.

7 States & Classification Thinking – Coastal Ecosystems

The floral and faunal biodiversity found throughout Madagascar is supported by a host of ecosystems, including rain forests, native grass and wood lands, mangroves, and coral reefs whose habitats are unique to the landscape and, in many cases, endemic. The island has historically been considered a biodiversity hotspot, but recent evidence suggests that a number of triggers, both natural and anthropogenic, are threatening the health of these landscapes, with potentially detrimental effects to the people who have come to rely on them (La Manach et al., 2012, McClanahan et al., 2009).

In response to the increasing pressures facing the social-ecological system of costal Madagascar, and in effort to more wholly understand and map the patterns of change, conservation agencies such as Blue Ventures have turned to a host of intervention strategies that aim to address both systems. The main goal is to either maintain or transform ecosystems so that they can perpetually exist and be strengthened, rather than decimated, by supporting the local social needs. This requires that the whole set of stakeholders, from local users, to policy makers, governmental agencies, researchers, non-governmental organizations and even non-users, understand and agree upon the parameters of interest, and the system variables that drive those parameters. As an illustration, villagers in Lovobe have found that the riverine mangroves immediately north of the village serve as a sheltering ground for the local brown mud crab population, especially in the months of April through June. As such, these months are witness to the highest degree of fishing in the mangroves. Through years of observation of catches, the locals have come to realize that following the spawning period of female crabs, which typically occurs in deeper waters during the warm, wet months, the ‘jennies’ and their juveniles migrate back to the fertile estuaries and settles in the muddy substrate, which is particularly deep in these mangroves. Local fishermen have come to use the depth of substrate as a sort of proxy for the health of the mangrove in months immediately prior to the heavy fishing season. During this time, unofficial management schemes and social pressures precluded builders from dredging the mangrove in order to make mud bricks, while fishermen took efforts to reduce the tidal wave energy leaving the

mangroves each day. Makeshift berms and dams were set up to slow the flow of water, although such efforts were also witness to increased turbidity in the areas of influence. The strategies undertaken might not have been optimal interventions, especially given the low technology available to the users, but nevertheless, the most relevant stakeholders all shared a vision of an optimal state of the riverine mangrove. This is the starting point or ground zero if you will, of Blue Ventures research through discovery framework, and the beginning of the attempt to understand the effect that these sorts of interventions are having on both the people who rely upon the brown mud crabs and the mangrove itself. This scenario is emblematic of the phrase social-ecological system.

7.1 Operational Definitions of State-and-Transition Modeling

State-and-transition modeling (STM), stemming from systems theory, frames a way of understanding the system parameters most important to the health and promulgation a particular ecosystem of study, as well as provides clarity on the level of understanding of the underlying variables that are the drivers of either ecological or social change.

The idea of defining an ecosystem “state” is a cognitive process that supports the development of a typology of ecosystems. Given the dynamics that have been found to exist within an ecosystem’s particular regime, state thinking allows researchers to give classification to any particular ecosystem being studied over a particular spatial and temporal scale (De Groot et al., 2002). Ecologically speaking, an ecosystem offers a unique set of functional operations and physical structure whose existence is owed to the unique interaction between a host of biological, edaphic, and hydrologic processes (Daily, 1997). Applications of STM have focused on a particular set of environmental variables, or biological attributes, that support the realized structure of the ecosystem. Each variable can be thought of as giving rise or being at least partially driving one or more environmental or socioeconomic functions that have value to either resource users or even non-users (Suding & Hobbs, 2009; Wilkinson et al., 2005).

In a state of equilibrium dominated neither by positive nor negative reinforcing feedbacks, the structure, composition and processes inherent in any system would stabilize and perpetually support the assemblage of species communities that came to adapt to the ecosystem (Walker, 1995). In such a rarified closed system the need for a typology of states would be null, as the ecosystem would only be witness to a single recognized state of being. Ecologists have long since demonstrated that such a state of perfect equilibrium rarely exists on most macro spatial scales. Furthermore, researchers

have offered that when left to their own devices, ecosystems such as mangroves and coral reefs are rarely in a state of equilibrium, but rather undergo successional changes driven by geomorphologic, hydrologic, biotic and climatic drivers (Woodroffe, 1992; Spalding et al., 2001). As an illustrative example, mangroves have been shown to be strongly influenced by naturally-occurring tidal conditions that, over time, trap sedimentation running off from rivers and coastal shorelines, thereby changing the structure of the mangrove over a period of decades (Lugo, 1991). The gradual development of an ecosystem is due to the combination of biological, geomorphic and hydrologic variables that give physical form and functional description to the ecosystem. Additionally, the parameters of the ecosystem itself, which are most often thought of as the system's features or properties, are an integral ecosystem component and can change the evolutionary path that ecologists have identified. Parameters are often quantifiable measures, such as ground cover, herbivorous fish species, forest structure, benthic cover, mammalian prevalence and diversity. Put another way, the variables of the system provide the stage on which the parameters can perform a natural transition that can be expedited or slowed by any number of anthropogenic influences.

The fundamental concept of an ecosystem transition, or undergoing a shift in structure, is based upon the premise that ecological systems can be shifted to alternatively stable states (Wilkinson et al., 2005; Walker & Salt, 2006; Bestelmeyer et al., 2003). Rooted in the theory of biological adaptation, the theory operates off the premise that the natural system undergoes a nearly constant response to dynamic, complex and, at times, non-linear stressors or perturbations that preclude the system of ever achieving equilibrium (Walters, 1997; Rogers, 1988). Depending on the spatial and temporal scale undertaken, the argument has been made that mangrove forests are undergoing a constant successional change (Lugo, 1980).

To elaborate, Lugo (1980) presented a theory on the successional state of mangroves by pointing to three primary drivers of change to the mangrove forests found in primarily in the New World. Specifically, he sought to address hydrologic conditions; time-scaled geomorphological changes and pulse events (such as a hurricane or cyclone) would drive coastal forests to exhibit alternative defined and delineated states. His research found that mangroves composition and functional siting can largely explain the various different settings, or states, that mangroves can occupy and still fall under the moniker of a mangrove. However, there are a handful of alternative states that the mangrove forest

can come to occupy if the driving conditions come together to support such a transition either short-term or long-term. Lugo observed that mangroves could transition to one of five successive states – terrestrial ecosystem, marine ecosystem, salt marsh ecosystem, hyper-saline ecosystem, and freshwater ecosystem. A successive state is one in which the ecosystem has evolved over time due to the changes in the environmental setting and the ecological and biological processes that are supporting the ecosystem. Lugo (1980), here, does not entertain the influence of human-induced transitions. Rather, the succession occurs because there is a gradient over which the biological processes exist. Instead, Lugo's argument on the succession of mangroves reinforces that change and response to changing system parameters is not necessarily a negative result, but rather, demonstrative of an ever-changing ecosystem.

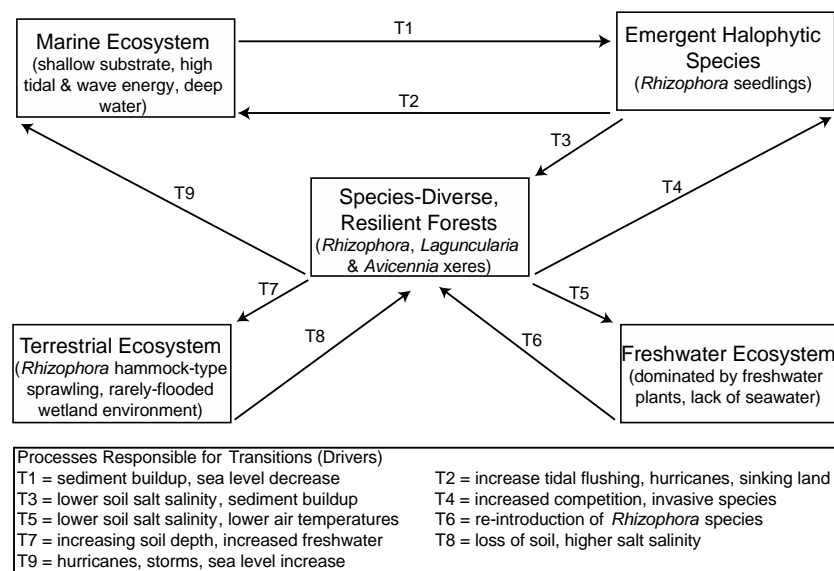


Figure 7: State-and-Transition Model of Mangroves (adapted from Lugo, 1980)

Functions of State-and-Transition Models

In practice, the effort required to manage either one or multiple social or ecological components to an intertwined system of interest requires that the investigators identify the ways in which an ecosystem responds to either the introduction or elimination of a particular stimuli, or driver, being targeted. State-and-transition models, in aiming to interpret and assess system responses, seek to categorize these responses through a series of exercises that engage each stakeholder and their level of knowledge. As offered by Bestelmeyer and colleagues (2009) and Nelson et al. (2007), effective STMs serve three primary functions.

- Contrast and compare the parameters of the references state to alternative states
- Describe the mechanisms through which a state undergo a shift to an alternative state
- Come to realize the points wherein a community-wide change is irreversible or otherwise requires prohibitively intensive energy or actions to return to the previous state

In the case of mangroves as described by first by Lugo and demonstrated in Figure 6, the parameters that were most of interest were the composition of the mangrove forest and the hydrologic and geomorphic settings in which it was found. These were deemed to be the most pertinent identifiers of reference when considering the succession of mangroves. The mechanisms believed to be most sensibly responsible for the shift to alternatively recognized ecosystem states were changes to the depth of the water table, increasing and decreasing levels of soil salinity and nutrients, and decreasing air temperature. The reversibility or irreversibility was considered in light of the opportunities that may be realized by particular combinations of mechanisms. For instance, Lugo and subsequent researchers have scientific reason to doubt that a mangrove ecosystem can transition directly from a marine-dominated environment straight to a species-diverse mangrove forest. There is, they posit, a transition to a state that exists between the two that is characterized by the emergence of halophytic trees, particularly *Rhizophora* xeres. Halophytic species have been shown to adapt to saltwater environments, and are able to grow and thrive amongst inundated watering conditions. Each of these functions seeks to understand the system's vulnerability and response to environmental changes. In recent years, these functions have proven to be dynamically interactive when imagined within a focused effort to elicit the resiliency of an ecosystem of interest.

Investigating the successional nature of mangroves offers an opportunity to distinguish between the concept of succession, which is rooted in the physical sciences, and the term 'alternative stable states', which introduces the relationship between the ecosystem and its social environment, which is rooted in systems theory. An alternative stable state is a term that is emblematic of the change to the configuration of a particular ecosystem, due in part to unnatural forces. Specifically, alternative stable states can exist outside, or in addition to, the successive states found in nature. As an example, climate change has shown to drive changes to air and seawater temperature, precipitation, levels of carbon

dioxide and even sea level rise, all of which have been shown to have a direct impact on mangroves (McLeod & Salm, 2006). In recognizing that climate change is largely due to human-based impact on the environment, the effects on mangroves and coral reefs are altering the natural progression of the ecosystems, forcing these natural systems to adapt to new environmental parameters and shifting the path of succession to new states. These alternative states can be either stable or unstable, depending upon the vulnerability of the organisms that provide the biological processes that are giving form to the new state. Therefore, the resiliency of the ecosystem, regardless of its current state, is of concern to stakeholders who wish to maintain or turn an ecosystem towards a healthy state.

In a way, each of the drivers can be at least partially sourced by human activity, but also can be controlled by future actions, given enough time – with the exception of natural disasters. However, in order to realize the influence that can be felt by the reduction of a particular driver, one must sometimes consider a scale that is one or more iterations larger than the immediate scale of focus. For instance, to decrease nutrient loading to coral reefs, the bordering and neighboring ecosystems are of particular interest. The same holds true for mangroves that are adjacent to a watershed that may have been recently converted to agricultural land. If local users wish to change the influence of nutrient runoff, they are faced with two options. First, they can themselves develop natural strategies to capture the nutrients prior to entering the mangrove by providing a natural buffer zone with vegetation. Otherwise, they can choose to engage their neighbors on ways to alter the structure of the watershed so as to decrease nutrient runoff. However, the conversation as to best land management practices that yield benefits to both parties is not only limited to neighboring communities. As was seen with the introduction of PES, interested parties a half a world apart can now engage in a conversation as to the costs and benefits of changing or maintaining the function of a particular ecosystem. The restrictions agreed upon by the managers of the Makira National Forest in terms of extracting trees from the rainforest were agreed upon by negotiating and balancing the needs of the local users with the benefits to which people all of the world would realize through the capturing of carbon. This discussion demonstrates that opportunity is not limited to carbon sequestration, but environmental services that can be scientifically linked to each and every driver demonstrated in Figure 6.

7.2 *Resiliency vs. Actor-Centered Frameworks*

The resiliency of an ecosystem is the ability of the ecosystem to absorb an impact, whether a one-time pulse, such as a cyclone, or a more time-dependent stressor, say increasing surface seawater temperatures, and yet still maintain its functional biological processes, structure and composition that lend it to being a “basin of attraction” (Walker & Salt, 2006). A resilient ecosystem can continue to support the ecological parameters found therein and the social reproductive and non-reproductive goods and services that either are or are not realized. Conservation-minded ecologists have developed the idea of resiliency as a functional definition of an ecosystem for more than a decade (see Walker & Salt, 2006; Walker & Salt, 2012; Kinzig et al., 2006). The resiliency of a particular ecosystem is a proxy, of sorts, for any social-ecological system’s 1) self-organization, 2) capacity for learning, and 3) ability to absorb change (Nelson, Adger & Brown, 2007).

A number of graphical descriptions demonstrating what is meant by an ecosystem state and how its resiliency characteristic directly relates to its vulnerability to undergo a transition, or cross a threshold, to an alternative state have been made (see Walker & Salt, 2006; Scheffer et al., 2001; Gunderson & Holling, 2002). In returning to the idea of a “basin of attraction”, the term seeks to elicit a visualization of the idea of an ecosystem state being thought of as existing within a basin. The basin is a funnel-shaped three-dimensional pictogram that describes the makeup of the ecological processes and structures, or the host of variables, that allow for the ecosystem to function and maintain its existence.

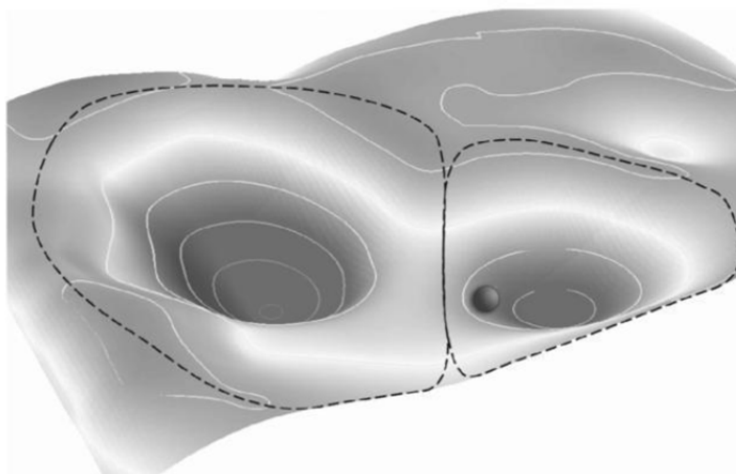


Figure 8: Ecosystem States as Basins of Attraction (figure reproduced with permission from Walker & Salt, 2006)

Each basin is surrounded by other basins, which are thought of as alternative basins of attraction. Each of the abutting basins of attraction shares a number of similar underlying ecological processes, structures, and drivers. However, each basin of attraction functions differently, due to either one or a number of alternative ecological or biological drivers. The threshold, then, is the point at which an imaginary ball, representative of the current state of the system, would move from one particular funnel-shaped basin of attraction over into a different basin (Walker & Salt, 2006; Gunderson & Holling, 2002). When the ball, or state, is at the bottom of the three-dimensional basin, it is thought of as being at a point of equilibrium. Here, the state is most stable, if you will, because it would take a greater perturbation or more prolonged amount of energy to move from the state out of the basin and across a threshold. Taken one step further, not all basins of attraction are identical. If a basin of attraction were thought of as relatively flat it would have a shallow basin. Naturally, it would require relatively little energy or perturbation to move the ball towards threshold. What was just described was a relatively volatile, or vulnerable, ecosystem. There may be any number of ecological reasons that a particular assemblage of biological processes is causing the characteristic vulnerability, which may not always be undesirable. If a mangrove were found to be in a degraded or alternative states such as a terrestrial ecosystem, and the goal was to drive the state back to a reference state, a more vulnerable ecosystem may react with less energy or effort on the behalf of the decision maker.

7.3 *State-and-Transition Modeling Towards Ecosystem Restoration*

Research of state-and-transition model has been used as a decision support tool that has aimed to measure the degree of success in restoring the vital parameters to ecosystems (Westoby et al., 1989; Bestelmeyer et al., 2009). This exercise in surveying a landscape for relevant parameters is emblematic of the move undertaken in recent years towards STM becoming a cognitive model that provides for an understanding of ecosystem restoration (Wilkinson et al., 2005; Suding & Hobbs, 2009; Yates & Hobbs, 1997). Two case studies are examined here, with both ecosystems in study exhibiting similar dynamics to two of the most important coastal ecosystems in Madagascar: mangrove forests and coral reef structure.

The study of the *Scalesia* forest cover by Wilkinson, Naeth, and Schmiegelow (2005) was undertaken on the island of Santa Cruz, one of the four main the Galapagos Islands, from the years 1997 through 2000. Ecological evidence gathered during the period of study posited that the *Scalesia* forest community was being decimated due to the introduction of invasive, foreign plant species as well as conversion of land cover for agriculture and pastoralist activities (grazing). Estimates of forest cover loss on the island were as high as 76 percent from pre-settlement to the year 2000. The forest community was undergoing a reorganization that was witnessing the soil cover being no longer able to continue to support the continued dominance historically witnessed by the *Scalesia* species. The objective of the restoration was to support a host of strategies aimed at placing the forested area on a trajectory towards an ecologically-desired reference state with variables such as “species diversity, abundance, and structure of uninvaded forest” (Wilkinson et al., 2005). With such an objective set, the modelers took to identifying and characterizing both the various states the landscape may adapt to, as well as the indicators of a transition between the states. A total of seven alternative states and eight transitions were identified. Each state had at least one parameter-controlled transition to an associative state that may appear characteristically similar to others, but fundamentally had different organization or supportability to the *Scalesia* species. The development of the exhaustive mapping of ecosystem states was undertaken with a host of social actors on the island, and in turn, the framework allowed for decision makers to “enact proactive management by maximizing restoration opportunities and minimizing obstacles”.

Willows (*Salix* spp.) are a perennial woody plant that grows at the natural border of inland riparian ecosystems of North America, most commonly along stream and riverbanks. Just as coral provides a number of biological services to its surrounding habitat, biologists have found that willows help to stabilize riverbanks, filter nutrient runoff to water sources and provide organic matter to streams, amongst others. Ecologists value the plant for providing a natural habitat to a number of plant and animal species, such as beavers who use its woody stock for both food and building material (Wolf et al., 2007). As such, two studies concerning the both the establishment and influence of *Salix* on hydrologic regimes in northern Wyoming (Bilyeu et al., 2008; Wolf et al., 2007) have been undertaken. Scientists in both studies were witnessing a perturbation, or stressor, being placed on the floral species, driven in large part to the overgrazing of willow by a burgeoning elk population and changing geomorphic and hydrologic settings within the fluvial ecosystems. The plant has seen a decrease of 60 percent over the past 100 years (Bilyeu et al., 2008). Wolf and colleagues (2007) suggested that climatic change, which may be responsible for warmer conditions, have exacerbated the problem of willow seedlings not being transported and established along downstream riverbanks. As riverbanks recessed, the native beaver was also forced to migrate to more sediment-rich floodplains, thus placing less upsetting the competitive balance on the willow plant. Both studies indirectly imagine a number of alternative ecosystem states comprised of the entire host of ecosystem variables, including elk, wolves, beaver and the willow plant, as well as ways to modify the parameters of the riparian zone, including damming of the rivers and reintroduction of the beaver. In conclusion, Wolf and colleagues described the elk-grassland ecosystem structure as an alternate, even stable, state that cannot support the objective of interest, the restoration of the willow plant and its host of ecosystem services. The move to a beaver-willow state is of primary intent, and could be akin to a reference state.

7.4 State-and Transition Modeling Applied to Coastal Seascapes

Scientists have recognized that coastal ecosystems are witness to complex dynamics that are not always linear in terms of both feedback processes and even the natural progression of the ecosystem (Woodroffe, 1992; McClanahan et al., 2009). The introduction of anthropogenic stressors upon the system can exacerbate the unpredictability of the seascape and require that researchers consider a number of ecosystem responses to particular demands. However, it is these same stressors that

are driving the changes to the ecosystems states and should, therefore, be understood in various different ecological and biological settings. Landscape-scale changes towards more vulnerable communities with poor resilience have been identified for both mangroves (McLeod & Salm, 2006; Lugo, 1981) and coral reefs (Bellwood et al., 2003). This underscores the fact that researchers seeking to understand the hydrologic, geomorphic, and ecological processes that drive a coastal ecosystem, such as mangroves, have to consider that the natural ecosystem can occupy various alternative states. While there are numerous examples of state-and-transition modeling being applied to terrestrial landscapes, there are not, until present, system-wide studies being applied to mangroves or coral reefs.

Mangrove States

There have been attempts made to clearly delineate mangrove states from other terrestrial and aquatic environments. This attempt was important given the natural evolution that mangroves undergo from aquatic environments during inception of a few halophytic species to the eventual terrestrial environment that results from excessive sediment buildup. In fact, ecologists have posited that mangroves, left to their own devices, tend to slowly expand the coastline while expanding seaward (Woodroffe, 1992; Lugo & Snedaker, 1974). Even absent the social-ecological connection, mangroves are witness to a number of natural stressors that can change the characteristic behavior of the mangrove and even, left unchecked, lead to a reorganization that presupposes an entirely different ecosystem type. Lugo (1981) developed a diagrammatic representation of the successional pathways that mangroves worldwide undergo. Considering solely the hydrologic and geomorphic influences of six mangrove profiles, Lugo identified ten successional mangrove states, each defined primarily by the composition and structure of the most common naturally-occurring plant species found in mangroves, *Avicennia*, *Rhizophora* and *Languncularia* (Combretaceae family). Empirical research from coastal Madagascar (Ravaoarinarotshihoarana, 2009) has shown that, while *Avicennia* and *Rhizophora* are indeed common to the region, *Laguncularia* is not often found on the southwest coast. Furthermore, of the profiles identified by Lugo (1981) and later studied by Woodroffe (1992), only four – riverine, hammock mangrove wetlands, scrub mangrove wetlands, and overwash mangrove wetlands – are supported by current landscape and climatic conditions. This underscores the importance of renewed research on not only the state of mangroves, but the transitional changes that

mangroves in southwest Madagascar face from not only natural stressors, but human-induced influences as well.



Figure 9: Evidence of Alternative Mangrove States of Belo-sur-Mer & Belo-Tsiribihina, July 2012
(photos courtesy of Dr. Garth Cripps)

The human impact of mangroves can result in dramatic changes to the structure and composition of the mangrove. The village of Belo-Tsiribihina is located 100 km north of Morondava, alongside the estuary and outlet of a major river and the Mozambique Channel. Being situated at the southern edge of Tsingy de Bemehara National Park, an international destination and UNESCO World Heritage Site, the region has become a tourism haven. The boom in activity observed in the past twenty years has had a detrimental effect on the mangroves that have been resource sources for a number of fish catches and building materials. The mangroves, today, are in a severely degraded state that shares resemblance to both marine and hyper-saline ecosystems absent of nearly all forest cover. This is evidenced in Figure 7, which juxtaposes the current state of a healthy, or reference, mangrove along an estuary in Belo-sur-Mer (image on the right) with the currently severely degraded state of an overwash mangrove in Belo-Tsiribihina, to the north of Morondava. The mangrove in Belo-Tsiribihina, in fact, may be undergoing or already have undergone a transition to an alternative state that more resembles a mudflat, rather than a wooded mangrove.

Coral Reef States

Coral reefs are subject to a number of alternative states, characterized most generally by the physical characteristics of the structure of the reef itself and relating such dynamics to specific biota baselines. Reefs have long been considered highly dynamic ecosystems that are adept at adapting to changing oceanic conditions, but recent

evidence suggests that this particular ecosystem is highly sensitive to warming water temperatures that have been observed on a worldwide scale (Hughes et al., 2003; Graham et al., 2006; Cinner et al., 2012). In Madagascar, coral-dominated reefs have historically been considered some of the most diverse found in the west and south Indian Ocean (McClanahan et al., 2009; Veron & Turak, 2005; Moberg & Folke, 1999), yet they also are witness to alternative, less healthy states due primarily to the effects of climatic change and additional anthropogenic stressors (Vincent et al., 2011; Nadon et al., 2005).

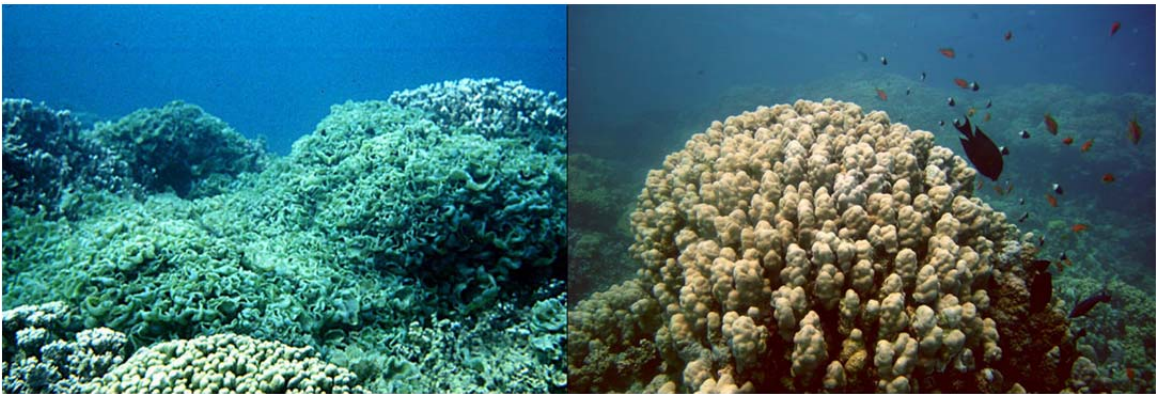


Figure 10: Alternative States of Coral Reefs (photo reproduced with permission of NASA Earth Sciences Data and Information Services Center)

Researchers have sought to reflect the relative state of coral reefs by considering three intertwining characteristics of the environment: the total amount, relative size and taxonomic diversity of coral and fish biomass present at a given point in time (Cinner et al., 2009; Graham et al., 2006; Smith, 1978). Most generally, the structure of the reefs is often characterized by the relative abundance of live, hard coral taxa with respect to a fleshier, algal-dominated environment structures. Indicators of a transition to alternative stable states often include relative number and diversity of large coral fauna and either and increase or decrease in herbivorous fish (Bellwood et al., 2004; Vincent et al., 2011). Nevertheless, there are three primary sitings of coral reefs that are found throughout southwest Madagascar (Nadon et al., 2005). Fringing reefs, which are the most common type of reef siting found throughout the world, grow extensively from the shoreline in southwest Madagascar, and demonstrate all three distinctive structures, including fore reefs near the coastline, a reef crest and outer reef (personal observation of the author – August 2013). The fore reefs have been observed to be separated from land by a series of lagoons and sea grass beds, which provide a buffer against sediment

and nutrient runoff from the low-lying mudflats and mangroves. The carbonate framework of the reefs is found growing primarily on a sandy substrate. To a lesser extent, a number of isolate outcrops of coral reefs, or patch reefs, also dot the seascape between Morondava and Toliara. Of course, the most prominent and well-known reef system, the Toliara Reef System, is actually a series of barrier reefs that exist in and around a number of near-shore islands in and around the Toliara area and just north of Morondava around the Barren Islands. The reef infrastructure was reportedly inclusive of approximately 750 fish species and 340 coral species at the turn of the century (Cooke et al., 2000), but recent empirical evidence suggests that the reef structure and fish composition have significantly decreased (Vincent et al., 2011; McClanahan, et al., 2009; Graham et al., 2006).

Generally, coral ecosystems can be thought of as occupying three alternative states, each largely characterized by the compositional makeup of the reef itself and the direct effect on benthic microorganisms that provide a food source for the sessile, coral polyps. Hardy, expansive macro fauna with a strong calcium carbonate base attached firmly to a substrate, such as rocks, is considered by marine biologists to be a “healthy” state. This is witnessed in the right-hand image of Figure 10. The coral composition that is strong, highly reproductive and increasing in diversity is an indicator of a number of variables, including healthy levels of algal and a supportive, positive feedback between benthic organism counts and herbivorous fish that live within the underwater environment. Absent any human stressors, reefs have shown the ability to reorganize and recover from various perturbations, including even coastal storms (Bellwood et al., 2004). However, coral reefs in intermediate or degraded states, both of which are considered “stressed” states, will see a number of biological-ecological interactions resulting in uncontained algal growth, the depletion of herbivorous fish. The inundation of the algal species prevent the reproduction of benthic organisms and the degradation of the live coral cover, as witnessed in the right side image of Figure 7. In its most degraded state the reef environment better resembles a barren rocky substrate absent of coral species, which never recovered from the stressors of invasive species and changing seawater conditions.

On the regional scale of the south Indian Ocean, Madagascar has been lauded for its relative richness in both coral condition and species diversity (Veron & Turak, 2005). However, more recent research has demonstrated that healthy ecosystems can undergo

both gradual and catastrophic shifts in both structure and function, resulting in a number of alternative stable, although unattractive, states (McClanahan et al., 2009; Scheffer et al., 2001).

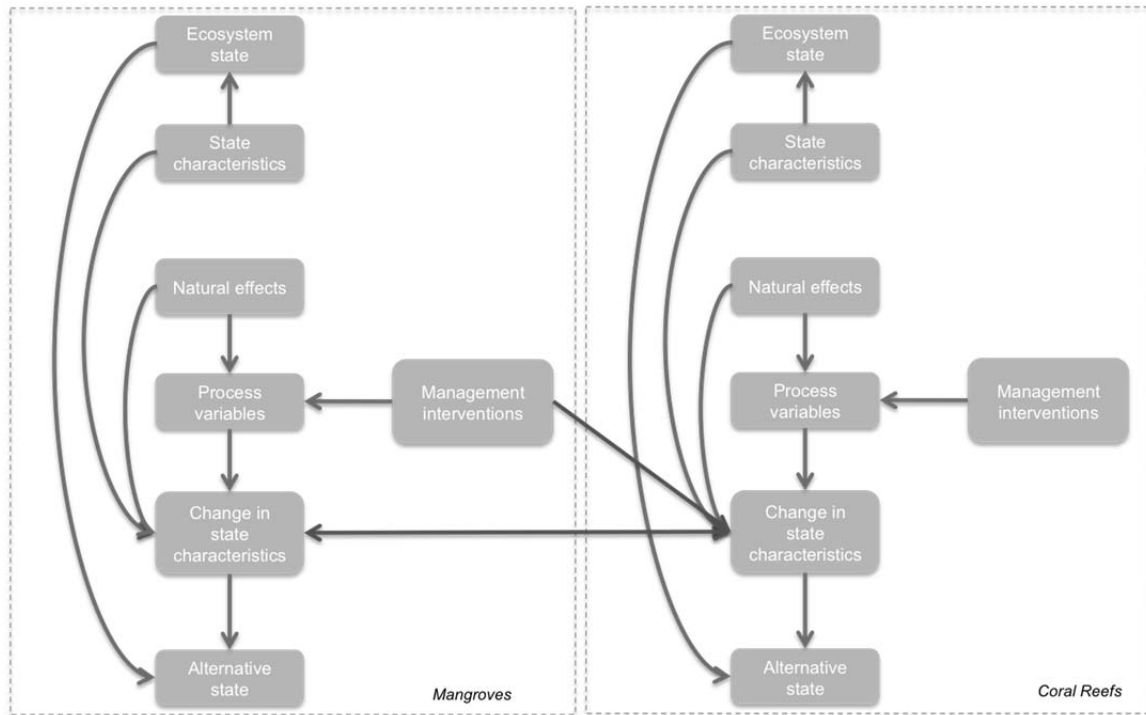


Figure 11: State-and-Transition Process Diagram (adapted from Rumpff et al., 2010)

Depending upon the spatial and temporal scales of interest for any particular study, it is reasonable to assume that any particular social-ecological system can occupy any number of alternative states, each being driven by a particular set of biological and ecological processes that are either strengthening or weakening the resiliency and adaptability of the ecosystem's structure and composition. The process variables are directly related to the characteristics of the ecosystem that support the perpetuation of realized natural resources. For instance, the calcification of carbon is the primary means in which reefs spread in many sandy environments. Scientific research has demonstrated that benthic algae, and particularly coralline red algae, can promote the production of up to 5.5 kg of carbonate production per year (Gattuso et al., 1998). The production of coral is a biological process that, most often, is supported by management interventions, in order to increase the amount of coral cover, and thereby, strengthen the supporting environment for fish. In this case, the variable supporting the production of coral is shown to be red algae, which lives inside the coral polyps. Kept in check by the

feeding of herbivorous fish, the variable that is algae production is often cited as a key driver towards the destructions of coral-dominated seascapes, when left unchecked (Bellwood et al., 2004). Thus, many management interventions, including those undertaken in southwest Madagascar, seek, in part, to promote grazing by herbivorous fish in order to keep algal counts in check (Vincent et al., 2011). As Figure 11 demonstrates, process variables such as algal growth, and state characteristics, such as the abundance of herbivorous fish, each play a hand in influencing the state of an ecosystem such as a coral reef. In recognizing this reality, the pressing question then becomes how, when witnessing an unsustainable or unattractive state, how the host processes and characteristics can be addressed and potentially change the projection and feedback that the ecosystem realizes. Furthermore, how can stakeholders assess whether their chosen interventions are effectively meeting their goals? The answers to these questions surrounding social-ecological systems and their interactions have increasingly been found in the use of adaptive management.

8 Adaptive Management as Tool for Fisheries Management

Southwestern Madagascar is a complex institutional setting in the developing world where the management, research and policy decisions are not often made in a vacuum, but have been shown to have very real and nearly immediate effects on both the social and environmental systems. Given the efforts already being made by organizations such as Blue Ventures, the author firmly believes that the situation in the region presents an opportunity to implement a comprehensively pragmatic and cooperative approach towards addressing both conservation of seaside natural resources and providing sustainable livelihoods; the process is known amongst researchers as adaptive management.

Adaptive management is a distinct governance methodology that is undertaken by ecosystem managers and decision makers who are charged with realizing a particular set of goods and services for a particular ecosystem or portion therein. The goods and services of interest are often diverse, as evidenced by mangroves, and therefore, require particular means in addressing the preservation or conservation of each. Adaptive management attempts to build consensus and find mutual objectives amongst a host of stakeholders from the physical and social sciences, to local management associations, governmental agents, and local users through opportunities to engage a host of

strategies that each aim towards a common goal. Placed within the framework of preserving the resiliency of an ecosystem facing environmental change, adaptive management has taken becomes increasingly recognized as adaptive environmental assessment and management (AEAM). Adaptive environmental assessment can best be thought of as a pragmatic approach to an identified or targeted stressor or driver of ecosystem states that is thought to be causing a shift in either the regime of a system or a movement towards an alternative state.

8.1 Why Adaptive Environmental Assessment and Management

Adaptive management practices find their theoretical root in the use of process, models that place feedback mechanisms at every stage in order to analyze the cause-and-effect relationship between the actor, or stakeholders, and the agent, the ecological system of study in this case. Adaptive management seeks to remove limits on understanding of hypothetical theories of the processes that underpin a particular system. In this way, adaptive management can be thought of as a cyclical, reiterative process of understanding cause-and-effect, rather than supposing a linear interpretation of the relationship between people and their environment. Both real and virtual feedback is made dynamic through an investigative analysis of data collected. This data will serve as active agent in the expansion of understanding on the part of the stakeholders and is used to shape future expected reaction or results. Applied to environmental systems, adaptive environmental assessment and management presupposes that social and ecological systems are interconnected and the purview of each perspective will have influence on the resiliency and response of a particular ecosystem of study (Nelson et al., 2007)

Fundamentally, adaptive management is an iterative approach to addressing an identified influential process or issue that may affect the current state of a particular system of study. Adaptive management seeks to test the relative percent probability of success or failure of a number of potential solutions onto a particular process or set of processes that may be underpinning or controlling the potential health or effectiveness of a particular system (Catford et al., 2013). In formulating expectations with regards to how an ecosystem will respond to a particular intervention, there is a degree of uncertainty about both the effect on the underlying processes driving the change in resources and the response of the ecosystem itself to the intervention strategy. Adaptive environmental assessment and management

Speaking regionally, aquatic and terrestrial ecosystems within Madagascar exist within a complex framework of local, regional and national management and jurisdictional settings. Each social grouping seeks to various degrees, the natural preservation of resources so as to preserve stocks for future generations while providing, at the very least, immediate economic and sustenance relief for primary users (personal observations of the author, June 2013). When putting these goals into practice, past conservation efforts on the part of international agents, such as Blue Ventures, Reef Doctor, Conservation International, and the World Wildlife Fund, have demonstrated a tendency for conservation-minded projects to follow a plan-act-monitor-evaluate cycle (Rougier et al., 2013; Belle et al., 2009). In turn, a number of use and restriction structures have been tested, such as seasonal closures (Benbow & Harris, 2009) and the establishment of marine protected areas (Belle et al., 2009), with various degrees of success witnessed. These mechanistic interventions have served two primary purposes. First, they seek to establish a fundamental understanding of the ecosystems that will, in turn, be used to make predictions about the impact of future ecosystem management policies (Walters, 1997). Secondly, they aim to engage a host of bureaucratic and political actors in both identifying goals and implementing single interventions.

Adaptive management can provide a cyclical process of continuously developing and reforming understanding about the resiliency and vulnerability of Madagascar's seascapes, rather than attempt to map out an ad-hoc set of final solutions that rely exclusively upon previous experiences and pre-set hypotheses to predict expected outcomes (Ostrom, 2007). Within the coupled social and ecological resilience perspective, a number of interconnected parameters of the ecosystem are recognized as vital to perpetuating or restoring the ecosystem to a healthy referenced state. At the onset of analysis, the proper functions of the referenced ecosystem are of primary interest to researchers. Naturally speaking, the biological processes that underpin the witnessed structure are identifiable. However, by coupling social systems to the function of the ecosystem, it becomes necessary to ascertain not only the drivers of structural identity of the ecosystem, but the positive and negative feedbacks that are occurring on both the lower (biological) and upper (social) levels. Lastly, it is important that surveyors and monitors develop an understanding of the development of the ecosystems on natural scales, so as to be able to differentiate between driven change and the ecosystems natural adaptability (Nelson et al., 2007). Adaptive management seeks to

understand and predict the positive and negative reinforcing loops between the cause of environmental change and the effects witnessed by the ecosystem.

8.2 Foundational Components of Adaptive Management

Development of “Learning by Doing”

Adaptive management first gained an audience in mid to late 1970s as researches began to better understand the effects of humans on natural ecosystems (Holling, 1973, 1978). Over the next fifteen years as the framework for ecological economics was being set, ecologists increasingly started to explore merging systems theory with ecology (Walters, 1986; Sainsbury, 1988; especially Rogers, 1998). Ecologists' study of nature, and the interactions that occur on both micro and macroscopic levels, have given rise to the classification of both aquatic and terrestrial ecosystems. What is often referred to as an “environmental setting” (Walters, 1997), is, in fact, the result of the study of the complexity of nature at various spatial and temporal scales (Norgaard, 2010). Ecological science is a deliberate attempt to understand the framework of natural systems (Díaz et al., 2011) but ecological theory alone does not have the predictive capacity that is often valued by bureaucratic and political decision makers who must consider the social-ecological system as a whole. As such, the development of general natural theory could not, supporters posited, alone improve the way that natural resources were managed (Walters, 1986; Holling, 1978). A most noteworthy result of the need for environmental and social scientists to link their fields of study and provide a vehicle for predicting ecosystem responses to both human and ecological facts was the Millennium Ecosystem Assessment (MEA), which when published in 2005, presented a framework within which “over fifty scholars and practitioners settled on and elaborated a dynamic, multi-scale systems view within which ecosystems were thought of as natural capital that provided ecosystem services, a stock-flow model” (Norgaard, 2010). The efforts of to infuse systems theory into the changing structure of natural ecosystems has also lead to the development of adaptive environmental assessment and monitoring (Schreiber et al., 2004), which is tool for monitoring and evaluating a host of social-ecological actions placed upon coastal and terrestrial ecosystems through a host of social actors, considered here as primary users. That is not the say that AEMA supposes an eclipsing of ecological questions, but rather, reframes the questions surrounding ecological systems by placing renewed emphasis on management-related questions (Schreiber et al., 2007).

Fundamentals of Adaptive Environmental Monitoring and Assessment

The development of adaptive environmental monitoring and assessment (AEMA) framework has centered about the need for stakeholders to structure decisions regarding ecosystems based upon the results of monitoring the ecosystem's response to an external stimuli or stress. The stimuli are intended to feed that reactionary information back to stakeholders and, ideally, shed light upon one or more areas of uncertainty (Schreiber et al., 2004; Ringold et al., 1996; Walters & Holling, 1980). The framework is an iterative cycle that has a number of well-defined stages, each of which is undertaken by one or multiple stakeholders, including users, decision makers, technical experts and modelers. The cyclical nature of the iterative process is aimed at exploring alternative ways of meeting a specified objective on multiple scales of intervention. In applying the scientific methodology to adaptive management, the investigatory process has been offered as either a six (Nyberg et al., 2006; Murray & Marmorek, 2003), or seven (Schreiber et al., 2004; Bearlin et al., 2002) step process. Both involve identifying goals of a particular intervention or action, measuring outcomes against stated goals, and evaluating the outcomes in relation to the overall objective of management (Schreiber, et al., 2004). However, in countering the notional belief that single best judgments are necessary to decision makers (Walters, 1997), and maintaining the value found in a model-based approach to AEMA, the process is framed here with a nod to Schreiber and colleagues (2004).

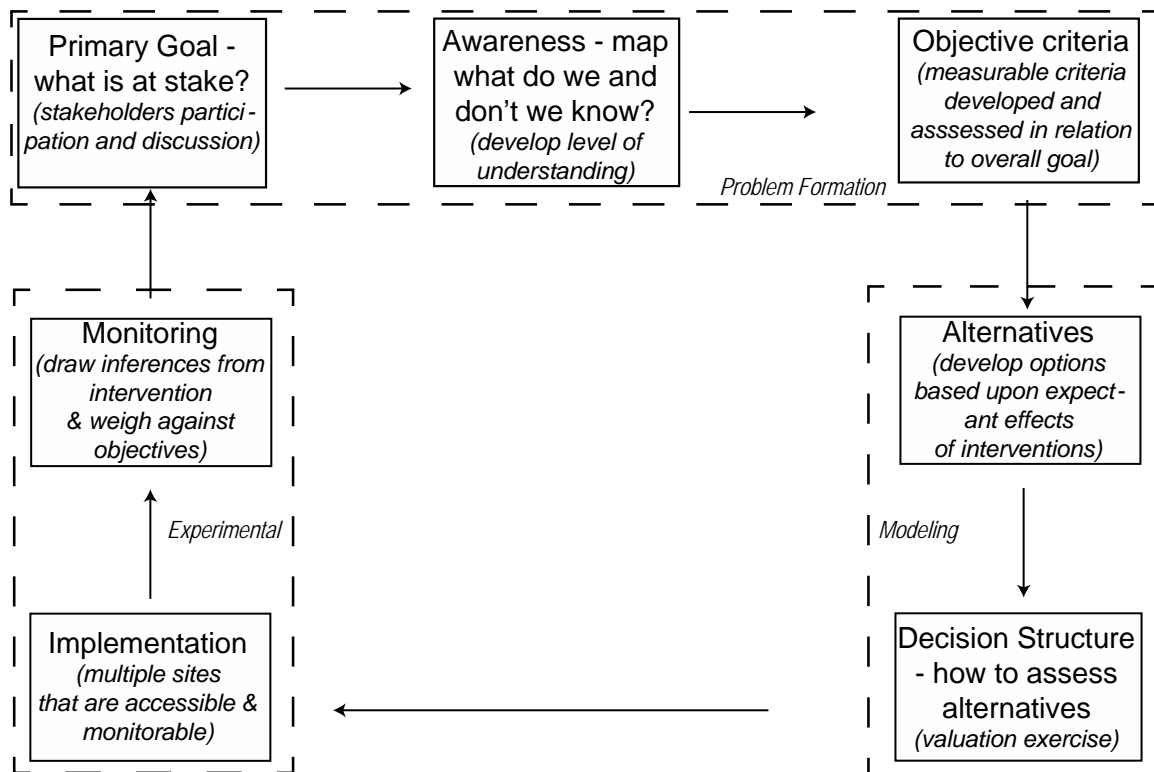


Figure 12: Fundamentals of Adaptive Management (Figure adapted from Schreiber et al., 2004)

The adaptive management approach to environmental monitoring and assessment has three categorical processes, the first of which is problem formation or planning. Forming, or framing, the problem around both social and ecological objectives comprises the first three steps of the process. The first step in AEMA seeks to define the management objective. This is an overarching principle of either conservation or use that the stakeholders would like to implement over a particular scale of both space and time. Practically, the objectives seeks to understand both what is of value to the most relevant stakeholders. Through this process, the constraints on the system will be explored, as well as the performance measures (Duncan & Wintle, 2008). Blue Ventures has undertaken this process in attempting to develop community management goals for coral reefs of the southwestern villages of Itampolo, Beheloke, Maromena and Befasy. Here, the researchers sought management objectives that were “realistic, measurable, and verifiable” (Gough et al., 2009b). For instance, the research team realized that a permanent restriction of capture fishing on the reefs was unrealistic, given both the structural need for the food and the lack of an authoritative entity such as a CBNRM with sufficient legitimacy in the communities. However, the idea of temporarily closing the reefs for a shorter period of time was deemed both acceptable and manageable through

the formation of informal and formal associations who monitored the grounds while closed. Similarly, Blue Ventures had to establish a monitoring program that measured fish count and catch size both before and immediate following the closure, using readily available measurement instruments, such as rulers and counter-balance scales. That way, the community would be able to both measure, and more importantly, verify localized conservation measures for themselves, once properly trained.

Secondly, AEMA considers the state of knowledge regarding both the social and ecological systems components, and their interconnectedness. Here, models are first used to map the current conditions of the social-ecological system structure and relations contained therein. All relevant stakeholders should disseminate the model in order to ensure both breadth and depth of understanding of system characteristics. In doing so, uncertainties, or key gaps in understanding, should be explicitly stated and, for the first time in the cycle, the system “adaptedness” – “the level of effectiveness in the way that the system relates with its environment” (Nelson et al., 2007) can be explored both qualitatively and quantitatively. In part, the modeler is attempting to determine the resilience of the system, as defined above. In the case of *Octopus Cyanea* preservation in Toliara, the LMMA realized that the near-shore reefs were being damaged by the fishing techniques employed in order to capture the invertebrates. Local and international scientists had developed a schedule or closure of various fisheries that followed closely with the gestational period of the octopus. However, there remains limited scientific understanding of the rate of reestablishment of coral communities. Local managers and Blue Ventures scientists have realized some regrowth occurring during the closures, but have not yet identified an optimal period for the restoration of healthy communities (G. Cripps, personal communication).

Thirdly, stakeholders are consulted to identify measurable goals, or the means of reaching the stated objective (Murray & Marmorek, 2003). These goals become the criteria that will be used to assess the host of alternate management options undertaken experimentally in step six (King & Hobbs, 2006). If the objectives specified in the first step of the cycle were the “what” question, then the goals relating to those objectives can be thought of as the “how” question (Murray & Marmorek, 2003).

The fourth and fifth steps of AM are critical in distinguishing active adaptive management from either traditional management interventions, trial-and-error learning (Gunderson & Light, 2006), or what is sometimes referred to as passive adaptive management

(Kingsford et al., 2011). The modeling category, which encompasses the fourth and fifth steps of the AEMA process, serves to first start to shape expectations about consequences of management options and then to start evaluating the decision structure for each of the alternate options (Addison et al., 2013). With AEMA, the model first attempts to identify alternate management options or interventions that address either one or more of the goals identified in step 3. In the case of adaptive harvest management of mid-continental mallard ducks in North America (Nichols & Williams, 2006), modelers reflected on two different hypotheses regarding the effect of hunting mortality to annual duck survival and two additional hypotheses about the strength of density-dependent relationship as an indicator of reproductive rate of the ducks. As such, researchers modeled four different management options – the fourth step of AEMA - that tested every possible combination of hypotheses, giving each possible combination equal weight. By weighing each combination of hypotheses equally, the researchers were indicating a fair degree of uncertainty in the decision and allowing the models to be calibrated on a yearly basis by comparing model outcomes against a comprehensive monitoring program undertaken each spring and fall in Canada. As data collected was measured against each of the four models, weighted combinations grew either larger or smaller, thereby allowing the management to decide which model would most likely result in “an optimal state-dependent regulatory strategy” (Ibid – p. 669). The fifth step of AEMA, then, is the in identifying the structure of the decision against which the formulaic expectations can be measured (Berlin et al., 2002).

The final two steps of AEMA are perhaps the most straightforward, in terms of cognitive understanding, but can also be the most human resource-intensive and problematic components to the AEMA process (Ringold et al., 1996). Collectively considered the experimental phase (Addison et al., 2013), the steps herein are critical for updating understanding and hypotheses of system characteristics, processes, and potential outcomes. The sixth step of the adaptive management process entails implementation of the host of alternate management options at either one site or multiple sites, depending upon the scale of interest (Walters & Holling, 1990; In the case of preservation of marine fish stocks in mangroves in southwest Madagascar, the implementation of alternate strategies could occur at multiple sites throughout the region. As of 2014, Blue Ventures was working on IDCP projects in a more than two-dozen villages, some with very small mangrove populations, such as Lovobe, while others within the Bay of Assassins, were practically surrounded by extensive mangrove growth. In Lovobe, the Blue Ventures site

manager and staff have worked to build an understanding of the connectedness between a healthy ecosystem and the health of women and children. The sole doctor in the village has integrated natural medicines sourced from the local mangroves for years, and locals have come to highly value this particular service. In capitalizing on this recognition, Blue Ventures has attempted a PHE program in order to meet the development needs of the village while simultaneously seeking to protect the natural environment (J. Bossert, personal communications).

The last step of adaptive management is to monitor the social-ecological system response to the management intervention (Schreiber et al., 2004). Monitoring of each alternate management option should be cognizant of characteristic of the system that the management option is monitoring and be consistent with the specified ecosystem management objective (Walters & Holling, 1990; Nyberg, et al., 2006). Murray and Marmorek (2003) make the clear distinction between operational (implementation) monitoring and effectiveness monitoring. Implementation monitoring can be important where the scale of focus is relatively large, stakeholders may only have remote access to the system of study, or the actions of both users and non-users may influence the outcome of the management option. The lack of implementation monitoring of the temporary closure of the riverine mangrove aide Lovobe from December to February 2013 resulted in users changing extractive methods and routines and ignoring the management decision. This is differentiated from effectiveness monitoring, which measures the whether or not the criteria and goals of the particular option are being met during and after implementation. In order for monitoring to be effective, two criteria must be met. First, monitoring must support the efforts of the decision makers to refine the specified objective based upon a better understanding of how the resource is being managed. Secondly, the monitoring process itself should evolve over time to better reflect the continuous refinement of means and methods of collection and analytic techniques most appropriate for the given environment. (Ringold, et al., 1996).

8.3 Adaptive Management – Practical Limitations

Fundamentally, adaptation is about recognizing the potential opportunity found in change while also embracing a level of uncertainty while management actions are being undertaken (Rumpff, et al., 2010; Keith et al., 2011; Nelson et al., 2007). In reality, both of these concepts have proven problematic when put into action (Conroy et al., 2011; Duncan & Wintle, 2008; Schreiber et al., 2004). While the resilience approach to

adaptation aims to reduce vulnerability of social-ecological ecosystems (Nelson et al., 2007), there are a number of barriers to use, as well as costs and risks borne upon the efforts, particularly during the experimental implementation and monitoring (Walters, 1997). In a seminal article in 1997, Walters suggested three sources of failures of modeling efforts to produce good experimental management plans and guide useful policy decisions: barriers to modeling for reliable assessment, costs and risks of large-scale management techniques, and lastly, self-interest in research and management organizations. By placing each of these barriers to use within the context of southwest Madagascar, possible solutions, including the use of state-and-transition modeling and Bayesian networks, to each of these conflicts may help provide a path forward for future conservation efforts aimed at social-ecological systems in the region. Once changes to the ecosystem structure are witnessed, the adaptedness of the processes and functions and ability to absorb these changes has proven problematic and in need of additional study. What's more, the effect onto a particular species or combination of resource-rich species, such as fish, to changes from both above (human intervention) and below (ecological processes) has proven to be source of study in uncertainty with regards to both drivers of change and system resiliency (Kingsford et al., 2011; Kinzig, et al., 2006).

Monitoring of ecosystem response plays an important role in adaptive management (Schreiber et al., 2004), particularly when a stimuli or controlling mechanism of a driver is the goal of the strategy. Whether managing counts of mid-continent ducks in North America (Nichols & Williams, 2006) or reopening hundreds of small-scale fisheries following a three-year NTA in central Chile (Castilla et al., 1998), the continuous nature of a monitoring scheme that assesses the goal of each imagined or implemented strategy against a central objective can be both costly and logistically challenging. Indeed, depending on both the spatial and temporal scale of interest, and the scope of strategy deployed for study, feedback to the system can be delayed or even misinterpreted. Therefore, it is imperative that monitoring design and evaluation be continuously evaluated and updated throughout. To date, adaptive management has been subject to limited evaluation within coastal ecosystems, and no studies have been undertaken of southwestern Madagascar's mangroves and coral reefs by employing adaptive management. However, it's clear that anthropogenic drivers, and particularly extraction of primary goods, are primarily responsible for changes seen to mangroves and coral reefs. Payment for ecosystem services demonstrates that managers believe it to be possible for local to monitor at least the extraction of trees from rainforests of

eastern Madagascar. If CBNRM associations in southwestern Madagascar can find consensus amongst users and sustain alternative livelihoods that do not require primary goods, then it may be possible to test a host of small-scale strategies for preserving both tree, coral and fish species.

One of the oft-cited criticisms of adaptive management is that by relying on manipulative experimentation and monitoring response, the costs of investment, both manual and monetary capital, in continual and large-scale research can be quite large. In addition, the host of strategies must be held accountable for any economic losses absorbed by the target populations (Walters, 1997). In the case of the mangrove closure occurring in Lovobe between December 2012 and February 2013, the majority of local fishermen, by respecting the temporary closure of the mangrove took it upon themselves to reintroduce a flow to a near barren rivulet because they presumably could not bear the economic plight of lack of income during the closure. In realizing the opportunistic risk, Blue Ventures has sought alternative means of livelihoods for fishermen and their families such as sea cucumber farming (Rougier et al., 2013), albeit at additional programmatic costs to the non-profit.

8.4 Synthesizing State-and-Transition Models as Adaptive Management Tool for Resiliency

Adaptive environmental assessment and monitoring has been developed and applied for a host of ecosystems whose structure and processes are represented and modeled with some degree of uncertainty, as it pertains to system's response to a particular intervention or disturbance. Adaptive management has increasingly come to "embrace uncertainty" (Keith et al., 2011) in studies of ecosystem function, such as the nestling patterns of parrots in response to poaching patterns (Briceño et al., 2011), changes to the ecosystem's capacity for both learning and absorption of change, such as southeastern Australian woodlands response to changing hydrological conditions in the Murray-Darling basin (Rumpff et al, 2011), and even addressing the producible services themselves, as Gunderson and Light (2006) addressed in their study of the Floridian Everglades. Each of these ecosystem types – Venezuelan rainforest, Australian grasslands, and American mixed wetlands – were studied to understand the characteristics, processes, and outcomes associated with adaptation actions aimed at biodiversity conservation. One of the central aims of each study was to return each ecosystem to a "state in which a system is effective in relating with the environment and

meets the normative goals of the stakeholders” (Nelson et al., 2007), or what Young and colleagues (2006) defined as the “adaptedness” of the ecosystem. In realizing a fair degree of fundamental resemblance and definitional synergy between state thinking and adaptive management, there has been increased effort in recent years to imagine how a cognitive process may present a structured mapping to the three primary processes – problem formation, modeling, and evaluation – that comprise the cyclical process that is adaptive management.

Each of the three categorical phases of AEMA has been targeted by a host of emergent modeling techniques that modelers have used to characterize and the social, economic and political elements to various complex ecological systems under threat. Models as simple as “box and arrow” diagrams such as Figure 7 can begin to give definition to both various states and drivers of change within a resilience-based approach to state-and-transition modeling (Wilkinson et al., 2005; Lugo, 1981). These alpha-level models have been used at the onset of AEMA undertaking to illustrate the “ecological causal web” of critical processes driving the currently witnessed characteristic structure of the ecological scale of interest (Marcot et al., 2006). In attempting to frame the various states of ecosystems and biological and environmental triggers, models that embrace uncertainty have recently turned to Bayesian belief networks to provide a theoretical framework for describing STM.

8.5 Bayesian Belief Networks in State-and-Transition Models

Bayesian belief networks have been warranted merited application to representing the current level of system knowledge as well as quantifying the uncertainty of causal-effect influences at each stage of the adaptive management process (Nyberg et al., 2006). Bayesian belief networks (BBNs) are now being used to answer three main questions posed by Ostrom (2007) in studying social-ecological systems by management strategies influencing both the resource and its users; the questions posed are:

1. What are the patterns of interactions and outcomes that result from a particular set of rules established for the governance or use of an ecosystem?
2. What are the likely endogenous developments that will arise in response to the implementation of the various governance structures?
3. How robust or adaptable is a particular combination of users and available resources?

Adaptive management implores modelers to explore these questions along every step of the process through an explicit monitoring design process developed at the onset of practice (Ringold, et al., 1996). Bayesian belief networks are increasingly being used to support the monitoring of the social-ecological system towards each of these valuable questions. For instance, McCann and colleagues (2006) used a beta-level mapping of a sub-basin of an interior western American forest in seeking to develop a baseline of understanding of the patterns of interactions between to exogenous processes, timber management and toad development, towards the habitat quality of the American marten. There have been a number of studies of terrestrial and mixed ecosystems under adaptive management schemes (Gunderson & Light, 2006; Rumpff et al., 2010; Duncan & Wintle, 2008), and the advancement of quantifiable tools such as Bayesian belief networks towards the elicitation of states and triggers (Nyberg et al., 2006; McCann et al., 2006; Smith et al., 2007).

Bayesian belief networks (BBNs) seek to use data gathered during a particular strategic intervention in order to test and update hypotheses about the effect that such intervention will have in realizing the vision of the overall strategy. Bayesian networks presuppose that there is a range of probabilities of an ecosystem occupying two neighboring states. The probability of an ecosystem, say a fringing coral reef, of alternating from a healthy single-species state to an algal-dominated state is contingent upon a number of environmental factors, process variables and current management actions, as shown in Figure 9. Changes to either one of these process variables can alter the direction of the reef and the probability of it either maintaining its current state or shifting towards another. Furthermore, the relative degree of influence of any particular process towards a particular state is often not known with utter certainty. These probabilities are often subjective, and depend upon the purview, education, and experience of each stakeholder. An example of a simple belief network that demonstrates the expected effect, or outcome, of the prevention of sediment runoff to the balance of food production through photosynthesis by algae living in the coral polyps.

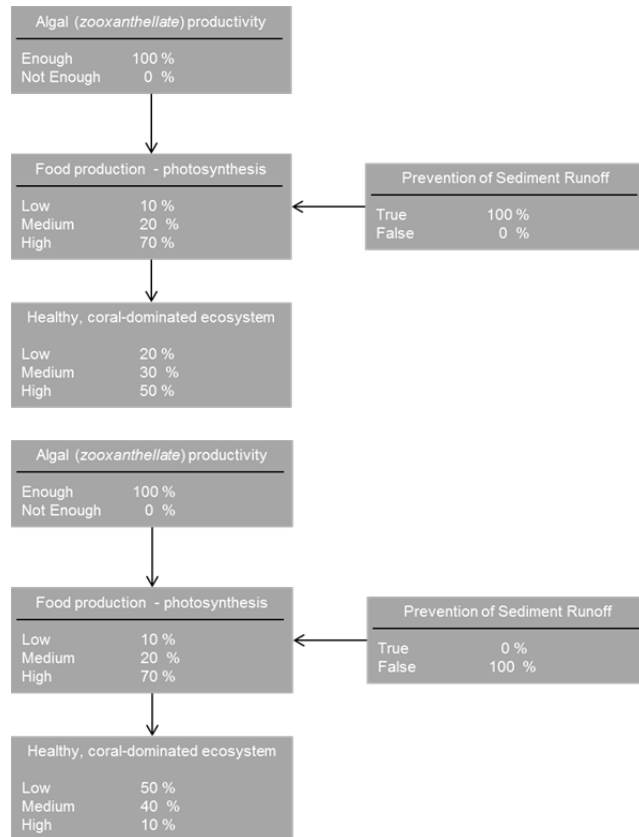


Figure 13: Bayesian Belief Network on Influence of Sediment Prevention on Coral Reefs

Clearly the effect of sediment and nutrients are subject to a number of biological and environmental factors, including the relative size and health of the coral reef, seawater temperature, prevalence of filter-feeding fish and mollusks such as oysters and a host of other factors. The productivity of algae is not the only factor that influences the production of food in the coral reef ecosystem. However, the probabilities assigned to the food production variable in this instance suppose that the productivity of algal heavily influences the production of food through photosynthesis. Others may posit that the contingent probability is either lower or higher, and thus the need to test and monitor both factors. The benefit of BBN is that it facilitates a discussion between stakeholder of not only the most relevant processes and effected state conditions, but also of the relative importance and influence of the management intervention onto the processes themselves.

The fundamentals of STM modeling approaches such as Bayesian belief networks to each of the seven phases of AEMA could be applied to coastal ecosystem in southwest

Madagascar, especially given the host of conservation measures that are being undertaken by a number of social actors.

9 Future Opportunities for Development in Madagascar

While there are real challenges in addressing the seascapes response to environmental and climatic change, as well as human activity, the study of the resiliency of each ecosystem can provide a lens of understanding about both the health of the ecosystem and the reproduction of its natural resources. In creating a frame of study that focuses on the resiliency of the ecosystem, emphasis is placed on two important elements of a healthy, productive seascape; namely, the vulnerability of the ecosystem with regards to a catastrophic shift in functional state, and the most important drivers of such dramatic change (Scheffer et al., 2001; Petraitis & Dungeon, 2003). The goal of this paper has been to suggest and encourage a strategy for conservation-minded actors currently working in southwest Madagascar to imagine a more robust management approach to conservation that both incorporates existing knowledge while recognizing and embracing their own degree of uncertainty.

9.1 *Data Shaping Strategies*

The fundamentals of adaptive environmental assessment and management, when properly synthesized, can help organizations such as Blue Ventures utilize quantitative modeling tools to move beyond simply “implementation monitoring” (Schreiber et al., 2004, Murray & Marmorek, 2003) and offer constant feedback to a host of experimental efforts. Simplistic conceptual models serve as a tool for measuring both the current level understanding of a particular ecosystem and can help the host of actors by explicitly articulating assumptions, identifying key uncertainties and thresholds and evaluating potential consequences to alternative management options (Schreiber et al., 2004; Nyberg et al., 2006). State-and-transition modeling that uses an Occam’s Razor to monitor and provide feedback to an adaptive management scheme for coastal ecosystems have allowed scientists to use the biological, ecological and social data gathered during experimental implementation (Rumpff, et al., 2010). In the case of seascapes, a number of environmental actors have been identified as critical to the natural succession of mangroves and coral reefs. The inadvertent shifting of mangroves and coral reefs, however, has also been driven by human interaction. Mangroves have

proven to be dependent on substrate and seawater conditions, which can be monitored and evaluated as driving towards or away a threshold into or out of a healthy ecosystem state. Healthy coral reef systems are more dependent upon their environmental siting, particularly their interaction with neighboring ecosystems such as mangroves and sea grass beds. Coral reefs also rely heavily on fish and invertebrates living amongst the reef structure to control both algal and aquatic plants by feeding on both. In both instances, limiting the human-induced stressors will help the ecosystems evolve and even recover naturally.

This case study demonstrates that monitoring of system responses can be a powerful tool that allows for updating of beliefs and provide a strategy for future management decisions that have the stipulated dual goal of environmental conservation and protection of social welfare (Duncan & Wintle, 2008). Overall, the flexibility in application of state-and-transition modeling make them appropriate tools for rapid development and discernment amongst a host of various actors at the village level and can aid in emphasizing the most critical drivers of ecological stress to be further investigated by both marine and social scientists in southwestern Madagascar.

9.2 Total Ecosystem Goods and Services of Seascapes

The aim of this paper was to present a framework for management of seascapes in southwestern Madagascar that are valued by local Vezo fishermen and resource users for a number of primary and secondary goods, including capture fish production, given the local emphasis on seafood as both a source of sustenance and economic opportunity. This is not to say that mangroves and coral reefs, along with sea grass beds, are only utilized for such primary products. However, there is hard evidence unearthed in studies in both Tanzania and the Solomon Islands that mangroves offer a host of primary goods and services to users that are far beyond just the extraction of seafood. In both Tanzania and Solomon Island, the elicitation of the management of mangroves not only broadened an understanding of the nature of harvesting goods, but also gave social scientists an opportunity to more roundly characterize the nature of livelihoods of both men and women.

To varying degrees, each good and service, whether consumptive or not, are sources of opportunity to the primary users for one reason or another. In effect then, each alternate management option developed within an AEMA cycle will affect the livelihoods that may not have been of initial purview. Blue Ventures has seen such “unintended

consequences” resulting from the temporary closures of mangroves in the village of Andavadoaka, where they came to realize that not just fishermen, but women and even children were engaged in the practice of catching *Octopus Cyanea* (Gough et al., 2009). In turn, Blue Ventures sought to establish alternative means of sustaining livelihoods for those women and children by introducing artificial reserves for the harvesting of sea cucumbers (Rougier et al., 2013). This case illustrates the importance of understanding the objective of any particular social-ecological system through stakeholder elicitation. As such, future research attention should turn towards a comprehensive assessment of ecosystem goods and services found within seascapes of southwest Madagascar. Such an understanding of the totality of the gain from these ecosystems would almost undoubtedly lead to the specification of a more nuanced and layered objective at the onset of the adaptive management cycle.

9.3 Coordination & Management of Multiple Efforts

Given Blue Ventures emphasis on data as a feedback mechanism and their focus on planning and design, the research team is ordered so as to avoid some of the major pitfalls historically befalling AEMA. There will be great challenges ahead, as conservation-minded organizations in Madagascar embrace emergent large-scale management experiments, such as payments for ecosystem services (PES) and population, health and environment (PHE) schemes. In 2013, the Malagasy government accounted through the Wildlife Conservation Society that more than 730,000 carbon credits had been certified; the credits were sourced from the Makira Forest in eastern Madagascar once WCS and local leaders received United Nations (US) Reducing Emissions for Deforestation and Forest Degradations Plus (REDD+) project certification. In February of 2014, WCS and Government of Madagascar announced the sale of these carbon credits to Microsoft Corporations and its carbon-offset partners (WCS, 2014), thus providing funding to protect the 400,000-hectare park. This project comes ahead of efforts by Blue Ventures in a similar vein in efforts to seek protection of the most densely populated mangrove forests in northwest Madagascar (Jones & Aigrette, 2012).

9.4 Monitoring as Central Tool for Development & Conservation

In returning to the story of the “no take” area (NTA) of the Lovobe reserve, the project effort failed for a number of reasons, one of which was the implicit decision made by both Blue Ventures and the village elders to engage in what amounts to simply

implementation monitoring. That is, they coordinated the establishing of the NTA, vocalized their support for the efforts and oversaw the placement of various signs to remind fishermen that they were not to enter the mangrove for harvesting purposes. From informal interviews of village members, there appeared to be widespread consensus about the potential value aimed at by the NTA process, and a general understanding of the ecological basis for the closure. It is offered here that the riverine mangrove, being small in both size and species diversity, was perhaps seen as being ecologically predictable, thus negating the need to consider a host of goals, which may have demonstrated the importance of the capture fish species to the daily subsistence of locals. However, even if this monitoring of compliance was enforced effectively, compliance efforts alone could not guarantee the success of the project. Evidence collected in preparation for this paper demonstrated that any number of parametric factors and community interactions from water level, soil salinity, surface seawater, and competing and invasive species, could be used to at least partially explain the success or failure of the NTA. Monitoring of the parameters identified early in the model development of both AM through state-and-transition modeling might serve to glean a better understanding of the state of the mangrove or coral reef system, and the needs of the society living aside it. Perhaps with a deliberate modeling effort aimed at the resiliency of the mangrove, various assessment criteria could have been developed that would have precluded attempting a number of sustainable options for the health of the social-ecological system. In turn, this paper proposed a management methodology that has been employed elsewhere in social-ecologically linked systems and sought to bring attention to its potential for influencing the direction of future focus onto coastal ecosystems, particularly those of southwest Madagascar. Specifically, the author supposes the management of fisheries in order to buffer both the resilience of three interconnected coastal ecosystems that aims to strengthen the health of the coast. In considering the duality of purpose – the preservation of both healthy ecological environmental and the sustainability of primary ecosystem goods and services – a pragmatic set of solutions whose effectiveness can be tested and subsequently bundled, will provide a more robust set of strategies for realizing both goals.

9.5 Recommendations for Implementation of AM + STM

The conceptual model proposed seeks to lay the groundwork for the development of a predictive model that is used to support decisions made surrounding the implementation

of IDCPs, particularly those in which Blue Ventures finds itself a stakeholder within the coastal ecosystems of southwestern Madagascar. Blue Ventures is currently at various stages of implementation of a number of complimentary IDCP measures, from integration of health and environment, to education, establishment of locally managed marine protection areas, and most recently, the introduction of the market-based incentive vehicle, PES. At each implementation siting, the IDCP strategy implored is done so after a thoughtful inclusive agreement as to the goal and objectives of the local villagers as they attempt to live a more sustaining lifestyle. In a similar vein, the state of the natural resources will also be a primary factor in the adoption and measuring of a particular strategy. For instance, a PEH program may not be the most effective solution for the village of Belo-Tsiribihina, where local resources have been decimated, leaving villagers to have to abandon their lifestyles and search for agricultural land. In a situation such as this, it may be of greater benefit to develop a community based natural resource management (CBNRM) association and attempt to establish a locally-managed marine preservation area around the most vulnerable and degraded mangroves. The general point here is that users and non-users can both benefit from the resources borne from mangroves, sea grass beds and coral reefs. The availability and reproduction of fish, propagules, seaweed, and other food, as well as wood and lime for construction, fishing materials, household items and fuel wood, depends upon the structure of the supporting ecosystem. The structure can only exist in a number of healthy states, and it is therefore of critical importance that the ecosystems be managed in such a way that precludes either the return to or perpetuating of a healthy social-ecological system.

The introduction of payment for ecosystem services offers a market-based incentive for local resource users to consider both the total and marginal benefits they receive from not only the primary goods, but the secondary goods and entire host of services that comes from mangroves, coral reefs, and sea grass beds. In fact, it is precisely the environmental services, such as carbon sequestration, that are incentivized most often, rather than primary goods such as capture fish species. Two challenges facing the implementation of PES are that of the scale of implementation and the definition of opportunity. With credit carbon prices, which are measured in cost per metric ton of CO₂, shrinking in recent years, the market has, in essence, decreed that the demand to lower emissions has lessened. If environmentally-minded companies such as Microsoft are continuing efforts to offset their carbon output through the purchasing of carbon emission credits, they will need to purchase more credits in order to meet a net carbon footprint.

This will require that greater stock of carbon sinks exist, which means that more healthy ecosystems that sequester carbon will be sought. If local resource users and managers are under pressure to realize this benefit to a greater extent, it will have a real effect on their management and use of the natural resources to which they depend. Therefore, the decisions made and IDCP strategies implemented must be aiming at returning degraded ecosystems such as the mangroves around Belo-Tsiribihina to a healthy state. In addressing the challenge of opportunity to the local resource users, agencies such as Blue Ventures and the Wildlife Conservation Society must develop locally-based intervention strategies that develop the capacity of the local people through reducing their dependence on the primary goods that are pressuring mangroves, sea grass beds and coral reefs. This has been partially realized through the development of alternative livelihood measures, such as the growing of artificial seaweed farms and the sustainable harvesting of sea cucumbers. As Figure 10 demonstrates, each ecosystem will change, both across a natural successional gradient and due to the anthropogenic interactions within the ecosystem.

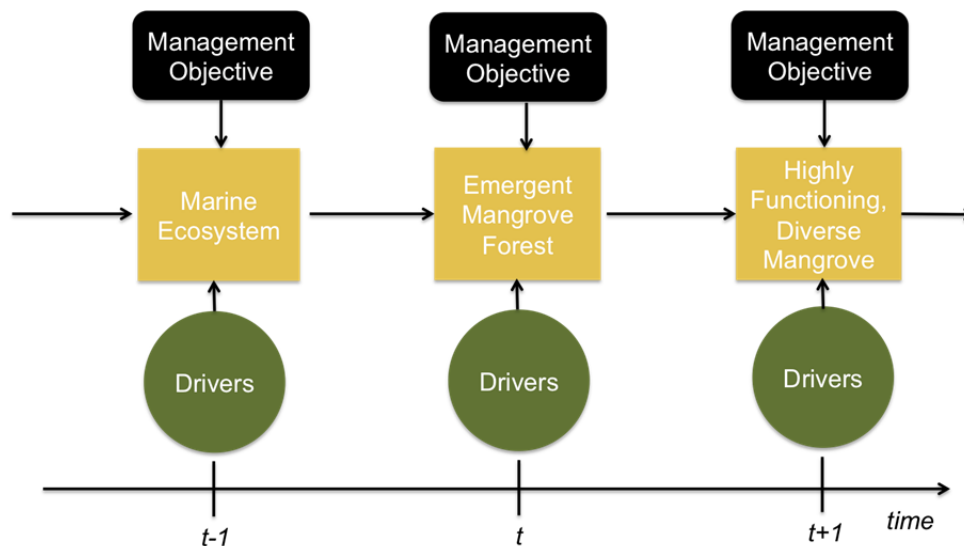


Figure 14: Change of Objective to Match Ecosystem State (adapted from Williams, 2011)

The strategy of developing adaptive management while using state-and-transition modeling can start to develop a predictability of ecosystem response to a number of management objectives and interventions. To be put into practice, researchers will have to closely monitor all aspects of the IDCP projects as they seek to return or perpetuate healthy coastal ecosystems. The next steps towards the realization of benefits by AM + STM is to focus on the drivers of ecosystem change by measuring those ecological and

biological characteristics that are thought to be most influencing the processes and giving definition to the current structure of the system. Adaptive management, in being an iterative process that is implemented on a number of small-scales, embraces the fact that the system may not exhibit the change predicted. Therefore, it is imperative that the all stakeholders constantly evaluate the primary management objectives for the current state and weigh the results against the overall vision of the IDCP. This paper supposes that the vision is a self-sustaining social-ecological system that nets benefits to both primary users and non-users alike. If PES is to be a viable IDCP strategy towards this vision, then local managers and researchers must double efforts to collect and monitor the drivers of ecosystem change, with a focus on the ecological response within an adaptive management framework.

10 Works Cited

- Addison, P.F.E., Rumpff, L., Bau, S.S., Carey, J.M., Chee, Y.E., Jarrad, F.C., McBride, M.F. & Burgman, M.A. (2013). Practical solutions for making models indispensable in conservation decision-making. *Biodiversity Review* **19**: 490-502. doi: 10.1111/ddi.12054.
- Alongi, D.M. (2002). Present state and future of the world's mangrove forests. *Environmental Conservation* **29**(3): 331-349. doi: 10.1017/S0376892902000231.
- Anthony, K. R., Kline, D. I., Diaz-Pulido, G., Dove, S., & Hoegh-Guldberg, O. (2008). Ocean acidification causes bleaching and productivity loss in coral reef builders. *Proceedings of the National Academy of Sciences*, **105**(45), 17442-17446.
- Antona, M., Bienabe, E. M., Salles, J. M., Péchard, G., Aubert, S., & Ratsimbarison, R. (2004). Rights transfers in Madagascar biodiversity policies: achievements and significance. *Environment and Development Economics* **9**(6), 825-847.
- Association Nationale pour la Gestion des Aires Protégées (ANGAP). (2002). Le Parc Nationale de Kirindy-Mitea. URL: http://www.parcsmadagascar.com/kirindy_mite/kirindy_mite.htm.
- Bearlin, A.R., Schreiber, E.S.G., Nicol, S.J., Starfield, A.M. & Todd, C.R. (2002). Identifying the weakest link: simulating adaptive management of the re-introduction of a threatened fish. *Canadian Journal of Fisheries and Aquatic Sciences* **59**: 1-8
- Belle, E.M.S., Stewart, G.W., De Ridder, B., Komeno, R.J.-L., Ramahatatra, F., Remy-Zephir, B., Stein-Rostaing, R.D. (2009). Establishment of a community managed marine reserve in the Bay of Ranobe, southwest Madagascar. *Madagascar Conservation & Development* **4**(1): 31-37.

Bellwood, D.R., Hoey, A.S. & Choat, J.H. (2003). Limited functional redundancy in high diversity systems: resilience and ecosystem function on coral reefs. *Ecological Letters* **6**: 281-285.

Bellwood, D.R., Hughes, T.P., Folke, C. & Nystrom, M. (2004). Confronting the coral reef crisis. *Nature* **429**: 827-833.

Benbow, S. & Harris, A., (2011). Managing Madagascar's octopus fisheries. Proceedings of the workshop on *Octopus cyanea* fisheries, 5-6 April 2011, Toliara. Blue Ventures Conservation, London.

Bestelmeyer, B.T., Tugel, A.J., Peacock, G.L. Jr., Robinett, D.G., Shaver, P.L., Brown, J.R., Herrick, J.E., Sanchez, H. & Havstad, K.M. (2009). State-and-transition models for heterogeneous landscapes: a strategy for development and application. *Rangeland Ecology & Management* **62**(1): 1-15.

Bilyeu, D. M., Cooper, D. J., & Hobbs, N. T. (2008). Water tables constrain height recovery of willow on Yellowstone's northern range. *Ecological Applications* **18**(1), 80-92.

Briceño-Linares, J.M., Rodríguez, J.P., Kathryn, M., Rodríguez-Clark, Rojas-Suárez, F., Millán, P.A., Vittori, E.G., Carrasco-Muñoz, M.C. (2011). Adapting to changing poaching intensity of yellow-shouldered parrot (*Amazona barbadensis*) nestlings in Margarita Island, Venezuela. *Biological Conservation* **144**: 1188-1193.

Casse, T., Milhøj, A., Ranaivoson, S. & Randriamanarivo, J.R. (2004). Causes of deforestation in southwestern Madagascar: what do we know? *Forest Policy and Economics* **6**: 33-48.

Castilla, J.C., Manríquez, P., Alvarado, J., Rosson, A., Pino, C., Espoz, C., Soto, R., Oliva, D. & Defeo, O. (1998). Artisanal "Caletas" as units of production and co-managers of benthic invertebrates in Chile. In: Jamieson, G.S & Campbell, A. (Eds): Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management. *Can. Spec. Publ. Aquat. Sci.* pp. 407-413.

Catford, J.A., Naiman, R.J., Chambers, L.E., Roberts, J., Douglas, M. & Davies, P. (2013). Predicting novel riparian ecosystems in a changing climate. *Ecosystems* **16**: 382-400. doi: 10.1007/s10021-012-9566-7.

Central Intelligence Agency. (2014). The World Factbook: Madagascar. Updated February 11, 2014. Accessed February 18, 2014: <https://www.cia.gov/library/publications/the-world-factbook/geos/ma.html>

Cesar, H. (1996). *Economic analysis of Indonesian coral reefs*. Environmentally Sustainable Development Vice Presidency, World Bank.

Cesar, H., Burke, L., & Pet-Soede, L. (2003). The Economics of Worldwide Coral Reef Degradation. Hague: Cesar Environmental Economics Consulting.

Cinner, J.E., McClanahan, T.R., Daw, T.M., Graham, A.J., Maina, J., Wilson, S.K. & Hughes, T.P. (2009). Linking social and ecological systems to sustain coral reef fisheries. *Current Biology* **19**: 206-212. doi: 10.1016/j.cub.2008.11.055.

- Conroy, M.J., Runge, M.C., Nichols, J.D., Stodola, K.W., Cooper, R.J. (2011). Conservation in the face of climate change: the roles of alternative models, monitoring, and adaptation in confronting and reducing uncertainty. *Biological Conservation* **144**: 1204-1213.
- Cripps, G. (2009). Understanding Migration Amongst Small-Scale Fishers in Madagascar. London: Blue Ventures Conservation Report.
- Daily, G.C. (Ed.).(1997). *Nature's Services: Societal Dependence on Natural Ecosystems*. Washington DC: Island Press.
- De Groot, R.S., Wilson, M.A. & Boumans, R.M.J. (2002). A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics* **41**: 393-408.
- Díaz, S., Fabien Q., Cáceres, D.M., Trainor, S.F., Pérez-Harguindeguy, N., Bret-Harte, M.S., Finegan, B., Peña-Claros, M. & Poorter, L. (2011). Linking functional diversity and social actor strategies in a framework for interdisciplinary analysis of nature's benefits to society. *Proceedings of the National Academy of Sciences* **108**(3): 895-902
- Donato, D.C., Kauffman, J.B., Murdiyarso, D., Kurnianto, S., Stidham, M. & Kanninen, M. (2011). Mangroves among the most carbon-rich forests in the tropics. *Nature Geoscience* (pub. online): 1-5. doi: 10.1038/NGEO1123.
- Duke, N.C., Meynecke, J.-O., Dittmann, S., Ellison, A.M., Anger, A., Berger, U., Cannicci, S., Diele, K., Ewel, K.C., Field, C.D., Koedam, N. m Lee, S.Y., Marchand, C., Nordhaus, I. & Dahdouh-Guebas, F. A. (2007). A world without mangroves? *Science* **317**: 41–42.
- Duncan, D.H. & Wintle, B.A. (2008). Towards adaptive management of native vegetation in regional landscapes. In: Pettit, C., Bishop, I., Cartwright, W., Duncan, D., Lowell, K., Pullar, D. (Eds.), *Landscape Analysis and Visualization. Spatial Models for Natural Resource Management and Planning*. Springer-Verlag, GmbH. pp. 159-182.
- Ellison, A.M. & Farnsworth, E.J. (1996). Anthropogenic disturbances of Caribbean mangrove ecosystems: past impacts, present trends, and future predictions. *BIOTROPICA* **28**(4a): 549-565.
- Elmqvist, T., Pyykönen, M., Tengö, M., Rakotondrasoa, F., Rabakonandrianina, E. & Radimilahy, C. (2007). Patterns of loss and regeneration of tropical dry forest in Madagascar: the social institutional context. *PLoS One* **2**(5): e402. doi:10.1371/journal.pone.0000402.
- Engel, S., Pagiola, S. & Wunder, S. (2008). Designing payments for environmental services in theory and practice: an overview of the issues. *Ecological Economics* **65**(4): 663-674.
- FAO Fisheries and Aquaculture Department.(2012). *The State of World Fisheries and Aquaculture*. Rome: Food and Agricultural Organization of the United Nations.

- Farley, J. & Costanza, R. (2010). Payments for ecosystem services: from local to global. *Ecological Economics* **69**(11): 2060-2068
- Gattuso, J. P., Frankignoulle, M., Bourge, I., Romaine, S., & Buddemeier, R. W. (1998). Effect of calcium carbonate saturation of seawater on coral calcification. *Global and Planetary Change*, **18**(1), 37-46.
- Giri, C. & Muhlhausen, J. (2008). Mangrove forest distributions and dynamics in Madagascar (1975-2005). *Sensors* **8**: 2104-2117.
- Goodman, S.M & Benstead, J.P (Eds). 2003. *The Natural History of Madagascar*. Chicago: The University of Chicago Press.
- Gough, C. Thomas, T., Humber, F., Harris, A., Cripps, G., & Peabody, S. (2009a). Vezo Fishing: An Introduction to Methods Used by Fishers in Andavadoaka Southwest Madagascar. London: Blue Ventures Conservation Report.
- Gough, C., Harris, A., Humber, F. & Roy, R. (2009b). Biodiversity and health of coral reefs at pilot sites south of Toliara. London: Blue Ventures Research Report
- Graham, N.A.J., Wilson, S.K., Jennings, S., Polunin, N.V.C., Bijoux, J.P., & Robinson, J. (2006). Dynamic fragility of oceanic coral reef ecosystems. *Proceedings of National Academy Science*, **103**(2), 8425-8429.
- Greber, K.v., RIngler, C., Rosegrant, M.W., Olofinbiyi, T., Wiesmann, D., Fritschel, H., Badiane, O., Torero, M. & Yohannes, Y. (2012). *Global Hunger Index*. Bonn: International Food Research Policy Institute.
- Gunderson, L.H. & Holling, C.S. (2002). *Panarchy: Understanding Transformations in Human and Natural Systems*. Washington: Island Press.
- Gunderson, L.H. & Light, S.S. (2006). Adaptive management and adaptive governance in the Everglades ecosystem. *Policy Sciences* **39**: 323-334.
- Holling, C.S. (1978). *Adaptive Environmental Assessment and Management*. Chichester: John Wiley & Sons.
- Hughes, T. P., Baird, A. H., Bellwood, D. R., Card, M., Connolly, S. R., Folke, C., Grosbert, R., Hoegh-Gulberg, O., Jackson, J.B.C., Kleypas, J., Lough, J.M., Marshall, P., Nyström, M., Palumbi, S.R., Pandolfi, S.R., Rosen, B. & Roughgarden, J. (2003). Climate change, human impacts, and the resilience of coral reefs. *Science* **301**(5635): 929-933.
- Humber, F. Harris, A., Raberinary, D. & Nadon, M. (2006). Seasonal closures of no-take zones to promote a sustainable fisher for *Octopus cyanea* (gray) in southwest Madagascar. London: Blue Ventures Conservation Report.
- Institut Nationale de la Statistique de Madagascar (INSTAT). (2012). Nombre de la population de Madagascar par Région et District de 1993 à 2011. Online URL: http://www.instat.mg/index.php?option=com_content&view=article&id=33&Itemid=56 [Accessed: 12 May 2013]

Jameson, S. C., McManus, J. W. & Spalding, M. D. (1995). *State of the Reefs: Regional and Global Perspectives*. Office of Ocean and Coastal Resource Management, National Oceanic and Atmospheric Administration, US Department of Commerce.

Jones, B. (2012). Socio-economic monitoring: a baseline assessment of the fishing villages of the Kirindy-Mite MPA. London: Blue Ventures Conservation Report.

Jones, T.P.G., Andriamarovololona, M.M., & Hockley, N. (2008). The importance of taboos and social norms to conservation in Madagascar. *Conservation Biology* **4**(2): 976-986.

Jones, T.P.G. & Aigrette, L. 2012. Towards finalizing areas of interest to assess the feasibility of REDD+ for Madagascar's mangrove forests. Blue Ventures Internal Report.

Kareiva, P. & Marvier, M. (2003). Conserving biodiversity coldspots. *American Scientist*, 91: 344-351.

Kathiresan, K. & Rajendran, N. (2005). Coastal mangrove forests mitigated tsunami. *Estuarine, Coastal and Shelf Science* **65**: 601-606. doi: 10.1016/j.ecss.2005.06.022.

Keith, D.A., Martin, T.G., McDonald-Madden, E. & Walters, C. (2011). Uncertainty and adaptive management for biodiversity conservation. *Biological Conservation* **144**: 1175-1178. doi: 10.1016/j.biocon.2010.11.022

King, E.G., & Hobbs, R.J. (2006). Identifying linkages among conceptual models of ecosystem degradation and restoration: towards an integrative framework. *Restoration Ecology* **14**: 369-378.

Kingsford, R.T., Biggs, H.C. & Pollard, S.R. (2011). Strategic adaptive management in freshwater protected areas and their rivers. *Biological Conservation* **144**: 1194-1203. doi: 10.1016/j.biocon.2010.09.022.

Kinzig, A.P., Ryan, P., Etienne, M. Allison, G. Elmqvist, T. & Walker, B.H. (2006). Resilience and regime shifts: assessing cascading effects. *Ecology and Society* **11**(1): 20. URL: <http://www.ecologyandsociety.org/vol11/iss1/art20/>.

Laroche, J., Baran, E. & Rasoanandrasana, N.B. (1997). Temporal patterns in a fish assemblage of a semiarid mangrove zone in Madagascar. *Journal of Fish Biology* **51**: 3-20.

Le Manach, F., Gough, C., Harris, A., Humber, F. Harper, S. & Zeller, D. (2012). Unreported fish, hungry people and political turmoil: the recipe for a food security crisis in Madagascar? *Marine Policy* **36**: 218-225. doi: 10.1016/j.marpol.2011.05.007.

Lebigre, J.M. (1984). Problématique de recherches sur les maraismaritimes de Madagascar en vue de leur protection et leur aménagement. *Revue de Géographie* **44**: 45-74.

- Lida, T. (2005). The past and present of the coral reef fishing economy in Madagascar: implications for self-determination in resource use. *Senri Ethnological Studies* **67**: 237-258.
- Lugo, A. E. (1980). Mangrove ecosystems: successional or steady state. *Biotropica* **12**(2), 65-72.
- Lugo, A. E., & Snedaker, S. C. (1974). The ecology of mangroves. *Annual Review of Ecology and Systematics* **5**: 39-64.
- Maina, J., Venus, V. & McClanahan, T.R., (2008) Modeling susceptibility of coral reefs to environmental stress using remote sensing data and GIS models. *Ecological Modeling* **212**(3): 180-199.
- Marcot, B.G., Steventon, J.D., Sutherland, G.D. & McCann, R.K. (2006). Guidelines for developing and updating Bayesian belief networks applied to ecological modeling and conservation. *Canadian Journal of Forest Resources* **36**: 3063-3074. doi: 10.1139/X06-135.
- Marikandia, M. (2001). The Vezo of the Fiherena coast, southwest Madagascar: yesterday and today. *Ethnohistory* **48**(1-2): 157-170.
- Mazda, Y., Magi, M., Kogo, M. & Hong, P.N. (1997). Mangrove on coastal protection from waves in the Tong King Delta, Vietnam. *Mangroves & Salt Marshes* **1**: 127-135.
- McCann, R.K., Marcot, B.G. & Eillis, R. (2006). Bayesian belief networks: applications in ecology and natural resource management. *Canadian Journal of Forest Resources* **36**: 3053-3062. doi: 10.1139/X06-238.
- McClanahan, T. R., Ateweberhan, M., Muhando, C. A., Maina, J. & Mohammed, M. S. (2007). Effects of climate and seawater temperature variation on coral bleaching and mortality. *Ecological Monographs* **77**(4): 503-525.
- McClanahan, T.R., Ateweberham, M., Omukoto, J. & Pearson, L. (2009). Recent seawater temperature histories, status, and predictions for Madagascar's coral reefs. *Marine Ecology Progress Series* **380**: 117-128, doi: 10.3354/meps07879.
- McLeod, E. & Salm, R.V. (2006). *Managing Mangroves for Resilience to Climate Change*. Gland (Switzerland): IUCN.
- Mittermeier, R.A., Myers, N. & Mittermeier, C.G. 2000. Hotspots: Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions. Washington, DC: Conservation International
- Ministère de l'Agriculture, de l'Elevage et de la Pêche (MAEP). (2003). Monographie de le Région de Menabe [Available online: <http://www.maep.gov.mg/newindex.htm>].
- Moberg, F. & Folke, C. (1999). Ecological goods and services of coral reef ecosystems. *Ecological Economics* **29**: 215-233.

Murray, C. & Marmorek, D. (2003). Adaptive management: a science-based approach to managing ecosystems in the face of uncertainty. Presented at the Fifth International Conference on Science and Management of Protected Areas: Making Ecosystem Based Management Work, 11-16 May 2003, Victoria, British Columbia.

Nadon, M.-O., Griffiths, D., & Doherty, E. (2005). The coral reefs of Andavadoaka, southwest Madagascar. London: Blue Ventures.

Nichols, J.D. & Williams, B.K. (2006). Monitoring for conservation. *TRENDS in Ecology and Evolutions* **21**(12): 668-674. doi: 10.1016/j.tree.2006.08.007.

Norgaard, R.B. (2010). Ecosystem services: from eye-opening metaphor to complexity binder. *Ecological Economics* **69**: 1219-1227. doi:10.1016/j.ecolecon.2009.11.009.

Nyberg, J.B., Marcot, B.G., Sulyma, R. (2006). Using Bayesian belief networks in adaptive management. *Canadian Journal of Forest Resources* **36**: 3104-3116. doi: 10.1139/X06-108.

Ogden, J. C. (1988). The influence of adjacent systems on the structure and function of coral reefs. In *Proceedings of the International Coral Reef Symposium, August 1998*: 123-129.

Ostrom, E. (2007). A diagnostic approach for going beyond panaceas. *Proceedings of the National Academy of Science* **104**(39): 15181-15187.

Patil, V., Singh, A., Naik, N., Seema, U. & Sawant, B. (2012). Carbon sequestration in mangroves ecosystems. *Journal of Environmental Research and Development* **7**(1a): 576-583.

Petratis, P.S. & Dudgeon, S.R. (2003). Detection of alternative stable states in marine communities. *Journal of Experimental Marine Biology and Ecology* **300**: 343-371. doi: 10.1016/j.jembe.2003.12.026

Raharimalala, O., Buttler, A., Ramohavelo, C.D., Razanaka, S., Sorg, J.-P. & Gobat, J.-M. (2010). Soil-vegetation patterns in secondary slash and burn successions in Central Menabe, Madagascar. *Agriculture, Ecosystems and Environment* **93**: 150-158.

Raharison, D. A. (2010) Travaux d'appui a l'etablissement de l'aire protegee marine et cotiere du sud Menabe: Etude d'Impacts Sociaux. KilyBe (Association du Andavadoaka).

Ravaoarinarotsihoarana, L.A. (2009). Ecological assessment of the mangrove forests of Kirindy Mite, Menabe, West Madagascar. London: Blue Ventures Conservation Report.

Reuters. (2014, January 3). Madagascar: election results released. The New York Times. Retrieved from: http://www.nytimes.com/2014/01/04/world/africa/madagascar-election-results-released.html?_r=0

Ringold, P.L., Algeria, J., Czaplewski, R.L., Mulder, B.S., Tolle, T. & Burnett, K. (1996). Adaptive monitoring design for ecosystem management. *Ecological Applications* **6**(3): 745-747.

- Rogers, K. (1998). Managing science / management partnerships: a challenge of adaptive management. *Conservation Ecology* **2**(2) [online]. URL: <http://www.ecologyandsociety.org/vol2/iss2/resp1/>.
- Rönnback, P. (1999). The ecological basis for economic value of seafood production supported by mangrove ecosystems. *Ecological Economics* **29**: 235-252.
- Rönnback, P., Crona, B., Ingwall, L. (2007). The return of ecosystem goods and services in replanted mangrove forests: perspectives from local communities in Kenya. *Environmental Conservation* **34**(3): 312-324.
- Rougier, A., Ateweberhan, M. & Harris, A. (2013). Strategies for improving survivorship of hatchery-reared juvenile *Holothuriscabra* in community-managed sea cucumber farms. *SPC Beche-de-mer Information Bulletin* #33: 14-22.
- Rumpff, L., Duncan, D.H., Vesk, P.A., Keith, D.A. & Wintle, B.A. (2011). State-and-transition modeling for adaptive management of native woodlands. *Biological Conservation* **144**: 1214-1223.
- Sainsbury, K.J. (1988). The ecological basis of multispecies fisheries, and management of a demersal fishery in tropical Australia. In: Gulland, J.A. (Ed). *Fish Population Dynamics*. pp. 349-382. New York: John Wiley and Sons.
- Scheffer, M., Carpenter, S. Foley, J.A., Folke, C. & Walker, B. (2001). Catastrophic shifts in ecosystems. *Nature* **413**: 591-596.
- Smith, C.S., Howes, A.L., Price, B. & McAlpine, C.A. (2007). Using Bayesian belief network to predict suitable habitat of an endangered mammal – the Julia Creek dunnart (*Sminthopsis douglasi*). *Biological Conservation* **139**(4): 333-347.
- Schreiber, S.G., Bearlin, A.R., Nicol, S.J & Todd, C.R. (2004). Adaptive management: a synthesis of current understanding and effective application. *Ecological Management & Restoration* **5**(3): 177-182.
- Smith, S.V. (1978). Coral-reef area and the contribution of reefs to processes and resources of the world's oceans. *Nature* **273**: 225-226.
- Spalding, M., Ravilious, C., & Green, E. P. (2001). *World atlas of coral reefs*. Los Angeles: Univ of California Press.
- Suding, K.N. & Hobbs, R.J. (2009). Threshold models in restoration and conservation: a developing framework. *Trends in Ecology and Evolution* **24**(5): 271-279. doi: 10.1016/j.tree.2008.11.012
- Tacconi, L. (2012). Redefining payments for environmental services. *Ecological Economics*, 73: 29-36.
- Thu, P. M., & Populus, J. (2007). Status and changes of mangrove forest in Mekong Delta: Case study in Tra Vinh, Vietnam. *Estuarine, Coastal and Shelf Science*, **71**(1): 98-109.

Tucker, B. (2012). Do risk and time experimental choices represent individual strategies for coping with poverty or conformity to social norms: evidence from rural southwestern Madagascar. *Current Anthropology* **53**(2): 149-180

Tyson, P. (2000). *The eighth continent: life, death, and discovery in the lost world of Madagascar*. London: William Morrow.

Veron, JEN & Turak, E. (2005). Zooxantheliascleractinia of Madagascar. In: McKenna, SA., Allen, GR (Eds), *A rapid marine biodiversity assessment of coral reefs of northwest Madagascar* [pp. 23-25]. Washington DC: Conservation International.

Vincent, I.V., Hincksman, C.M., Tibbetts, I.R., Harris, A. (2011). Biomass and abundance of herbivorous fishes on coral reefs off Andavadoaka, Western Madagascar. *Western Indian Ocean Journal of Marine Science* **10**(1): 83-99.

Walker, B. (1995). Conserving biological diversity through ecosystem resilience. *Conservation Biology* **9**: 747-752.

Walker, B. & Salt, D. (2006). *Resilience Thinking: Sustaining Ecosystems and People in a Changing World*. Washington DC: Island Press.

Walker, B. & Salt, D. (2012). *Resilience Practice: Building Capacity to Absorb Disturbance and Maintain Function*. Washington DC: Island Press

Walters, C. (1986). *Adaptive Management of Renewable Resources*. New York: Macmillan.

Walters, C. (1997). Challenges in adaptive management or riparian and coastal ecosystems [online]. *Ecology and Society*, **1**(2): 1. [Online] URL: <http://ecologyandsociety.org/vol1/iss2/art1/> [accessed March 4, 2013].

Walters, C. J., & Holling, C. S. (1990). Large-scale management experiments and learning by doing. *Ecology* **71**(6): 2060-2068.

Warren-Rhodes, K., Schwarz, A., NG Boyle, L., Albert, J., Agalo, S.S., Warren, R., Bana, A., Paul, C., Kodosiku, R., Bosma, W., Yee, D. Rönnbäck, P., Crona, B. & Duke, N. (2011). Mangrove ecosystem services and the potential for carbon revenue programmes in Solomon Islands. *Environmental Conservation* **38**(4): 486-496.

Westoby, M., Walker, B. & Noy-Meir, I. (1989). Opportunistic management for rangelands not at equilibrium. *Journal of Range Management*, **42**(4): 266-274.

Wilkinson, S.R., Naethe, M.A., Schmiegelow, F.K.A. (2005). Tropical forest restoration within Galapagos National Park: application of a state-transition model. *Ecology and Society* **10**(1): 28. [Online] URL: <http://www.ecologyandsociety.org/vol10/iss1/art28/> [Accessed 21 January 2014]

Wildlife Conservation Society. (2014). Madagascar sells first forest carbon credits to Microsoft [Press release]. Retrieved from <http://www.wcs.org/press/press-releases/microsoft-buys-carbon-credits.aspx>

Williams, B.K. (2011). Adaptive management of natural resources – framework and issues. *Journal of Environmental Management* **92**: 1346-1353.

Wolf, E. C., Cooper, D. J., & Hobbs, N. T. (2007). Hydrologic regime and herbivory stabilize an alternative state in Yellowstone National Park. *Ecological Applications* **17**(6), 1572-1587.

Woodroffe, C. (1992). Mangrove sediments and geomorphology. *Coastal and Estuarine Studies* **41**: 7-41.

Wunder, S. (2005). Payments for environmental services: some nuts and bolts. *Ocasional Paper No. 42*. CIFOR, Bogor.

Yates, C.J & Hobbs, R.J. (1997). Woodland restoration in the Western Australia wheatbelt: conceptual framework using a state and transition model. *Restoration Ecology* **3**: 67-86.

Young, O.R., Berkhout, F., Gallopín, G.C., Janssen, M.A., Ostrom, E. & van der Leeuw, S. (2006). The globalization of socio-ecological systems: an agenda for scientific research. *Global Environmental Change* **16**: 304-316.