



Ecosystem Services Valuation of mangrove forests in the Zambezi Delta MOZAMBIQUE



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World Wide Fund for Nature - Mozambique Country Office

UEM – Eduardo Mondlane University



Ecosystem Services Valuation of mangrove forests in the Zambezi Delta

MOZAMBIQUE

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Abstract

The Zambezi Delta is an alluvial triangular shaped plain, about 120 km long towards the coast and 200 km along the coast, covering an area of about 12,000 km² with several branches and mangrove creeks. The mangrove area is about 37,034 ha, as per year 2014. The Delta hosts an important rich and diverse ecosystem with endemic fauna and flora. In particular, the extensive mangrove creeks and estuaries are a nursery and breeding ground to important fisheries. These ecosystems sustain important resources including fisheries and agriculture and extensive grazing lands that provide major source of food and employment for the population living in the Delta. Approximately 188,206 people, out of which 50.5% are women, live in the Delta, and gain their living mainly out of agriculture, fisheries and mangrove wood harvesting. The mangrove direct and indirect resources are the major foothold of the livelihood in the Delta. Though mangroves in the delta are relatively pristine there are threats both of natural as well as anthropogenic nature. The ignorance about ecological value of mangrove may hamper the efforts for their sustainable use and conservation, hence, the present study of economic assessment of the ecological value of mangroves, commissioned by WWF-MCO with the support of the Blue Forests Project, with the aim of raising awareness on the importance and value of the mangrove ecosystem in the Zambezi Delta, fostering conservation and adoption of sustainable management measures of these important ecosystems. A rapid ecological-economic-livelihood assessment methodology to calculate the monetary value of mangroves, considering both its use and non-use values, direct and indirect use, was applied. The economic valuation techniques used considered the cost-based of replacement, effects on production and damage avoided. Data were obtained through semi-structured interviews targeting households, markets and artisanal fishery centers; 573 households distributed in 12 villages, in the district of Chinde and surroundings were interviewed; and through government official statistics; data on fish catches were obtained from the National Institute for Fisheries Research (IIP) reports of 2014. In addition, the information on maritime transport, major routes, goods transported, value, carbon sequestration and trading were collected. The data and information were recorded and processed in Excel. GIS was applied to map the surveyed locations. The result indicated that the direct use of mangroves in poles, timber, firewood and charcoal yield was estimated at 1,120 US\$ ha⁻¹ yr⁻¹ on average; the regulating, habitat and nursery and climate regulation functions were estimated at 20,000 US\$ ha⁻¹ yr⁻¹, 600 US\$ ha⁻¹ yr⁻¹ and 6,000 US\$ ha⁻¹ yr⁻¹, respectively. Considering the total area (37,034 ha) of mangrove in the Delta, the direct use of mangrove worth 41,478,080 US\$ yr⁻¹ and the indirect use of mangrove worth 985,104,400 US\$ yr⁻¹ for the entire Zambezi Delta. Thus, the overall mangrove value in the Zambezi delta is estimated at 1,026,582,480 US\$ yr⁻¹. Hence, the indirect benefits, those from ecosystem services, worth 98.4% of the total value of mangroves in the Zambezi Delta. The net Income due to direct mangrove use, mainly from poles and charcoal, was estimated at 79 US\$ ha⁻¹ Month⁻¹ per household, and due to indirect use of mangroves, mainly from fisheries, was estimated at 308 US\$ ha⁻¹ Month⁻¹ per house hold. The study showed that mangroves render more to people if are conserved, used sustainably and using only the products derived from their ecosystem services. There were evidences of potential threats to sustainable exploitation of mangrove and associated resources, given the current trends in population pressure. Hence, the study recommends the promotion of alternative livelihood to cutting of mangroves. The suggested alternative livelihoods are agriculture, rehabilitating the irrigation system of Sombo; fish processing and trade; cage aquaculture; crab fattening and trade; and bee keeping.

Keywords: Mangrove ecosystem, ecological value, monetary value, yield, household, conservation, livelihood, Zambezi delta, Mozambique.

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Glossary

CICES	Common International Classification of Ecosystem Services
ES	Ecosystem Services
GEF	Global Environmental Facility
GIS	Geographic Information System
IIP	National Institute for Fisheries Research
IUCN	International Union for Conservation of Nature
MEA	Millennium Ecosystem Assessment
MICOA	Ministry for Coordination of Environmental Affairs
Ramsar	The Ramsar Convention on Wetlands
SEEA	System of Environmental-Economic Accounting
TEEB	The Economics of Ecosystems and Biodiversity
TEV	Total Economic Value
UEM-ESCMC	Eduardo Mondlane University, School of Marine and Coastal Sciences
UNESCO	United Nations Educational, Scientific and Cultural Organization
WWF-MCO	World Wide Fund for Nature – Mozambique Country Office

1. Introduction

This report provides a rough assessment of the economic value of the mangrove ecosystem services (ES), discusses options and advances some policy recommendations for sustainable use and conservation of mangrove resources in the Zambezi Delta. Whereas the results were derived from the case study of the mangroves of the Zambezi Delta they can be applied elsewhere with similar conditions.

Assessment of the economic value of the mangrove ecosystem services and subsequent determination of the related socio-economic benefits they provide is critical for decision makers, to make well-informed decisions, in development planning, wise use of the land and water resources and in directing investments for sustainable development of the local communities and in the management of the ecosystems and their services. Hence, the World Wide Fund for Nature – Mozambique Country Office (WWF-MCO) with the support of Blue Forests Project is undertaking a project on “Application of the Blue Forests methodologies and approaches through small-scale interventions in Mozambique”, under the Blue Forests Initiative and Sustainable Financing of Protected Areas of Mozambique, and commissioned the present study for economic assessment of the ecological value of mangrove in the Zambezi Delta. The study was technically carried out by the UNESCO Chair of Marine and Coastal Sciences of the Eduardo Mondlane University, hosted at the School of Marine and Coastal Sciences of Quelimane, Zambezia Province.

The overall objective of the project is to assess and estimate economic value of ecosystem services provided by mangrove forests in the Zambezi Delta, Mozambique. The scope of the project is the mangrove area of the Zambezi Delta, particularly key community villages nearby Chinde District (northern branch of Zambezi Delta). The findings of this study are expected to create awareness on the importance and value of the mangrove ecosystems to the government, private sector and donor community thereby catalyzing investment in the rehabilitation and protection of these ecosystems. This work reflects on what is envisaged in Mozambique’s Environmental Master Plan and the Zambezi River Management Strategy, all contributing to Mozambique’s Vision 2030.

The study contributes to an economic assessment of the mangrove ecosystem services and evolves around an extended cost benefit analysis taking into account the environmental and social benefits. The ecosystem services provided by the Zambezi Delta mangroves was valued considering the *diversity of ecosystem services* affected throughout the mangrove and mangrove creeks and estuaries, thereby calling for a comprehensive analysis accounting for *mutual dependencies*. The study made distinction between the mangrove use that involves the destruction of mangrove such as timber, firewood and charcoal from those that require the conservation of mangroves such as the fisheries. Assessment of the contribution of the ecosystem services to the household income of the people living in the Delta was made as to contribute to raising awareness on the importance of the ecosystem to the local communities. This study discusses further, the threats, management issues and alternative livelihood options to the cutting of mangroves, hoping to provide some useful information for policy makers, practitioners and local communities that operate in the Delta.

The overall questions addressed in the present study were as follows:

- What are the direct values of different mangrove ecosystem products (e.g. fish, crustaceans, molluscs and other products)?

- What are the indirect values of different mangrove ecosystem services (e.g. coastal protection and fish habitat)?
- How are the economic and financial benefits of different mangrove goods and services distributed between different beneficiaries (e.g. local communities, regional/province economy, National economy, etc)?
- What would be the economic and livelihood impact over time of continued mangrove loss?
- What is the economic rationale for mangrove rehabilitation and management?

The information in the present study should be considered as an effort to combine information that is highly scattered and often hard to access. In this manner, the study hopes to serve as the basis for subsequent in-depth studies. Further, the team acknowledges that despite the major efforts put into collecting all relevant information, given the multidisciplinary nature of the study and scarcity and dispersive nature of the data, there might be some relevant information missed out.

The remainder of this report will elaborate further on the various sub-components of the research, as listed in the sub-objectives above. Chapter 2 explains the background of the study and review the economic value of the ecosystem services of mangroves in general and the methodologies commonly used for their assessment as obtained from the literature; Chapter 3 provides the description of the biophysical characteristic of the Zambezi Delta; Chapter 4 presents the methodology applied in the present study; Chapter 5 presents the result of the present studies related to economic ecological value of mangroves in Zambezi Delta. Chapter 6 presents the results of the perception of the households on the value of mangroves whereas Chapter 7 presents the results of the household income, as obtained from the interviews. Chapter 8 presents threats and drivers to mangroves and associated resources. Chapter 9 presents the policy recommendations and options for sustainable mangrove use in Chinde, as a result of the present study. Chapter 10 discusses the overall results and Chapter 11 presents the overall conclusions and recommendations for future studies.

2. Background

2.1. Project Context

The Global Environmental Facility (GEF) Mozambique Blue Forests Project is part of a coordinated international effort to demonstrate methodologies for carbon accounting and ES valuation in blue carbon ecosystems. Blue Carbon ecosystem refers to the functional attributes of coastal and marine ecosystems to sequester and store carbon.

The project is part of a coordinated effort to provide evidence-based experience that support replication, up-scaling and international adoption of blue forests concepts. Nationally, this project represents an opportunity for Mozambique to improve its understanding of ecosystem services, including carbon sequestration, storage, avoided emissions and management in mangrove ecosystems in the Zambezi Delta.

The application of blue forest methodologies and approaches will also result in overall improved ecosystem management for the Zambezi Delta allowing an exploration of the valuation of ecosystem services for mangroves in the Zambezi Delta and promote the sustainable use of mangrove resources in order to meet the needs for the local communities through activities such as beekeeping, crab fattening, the establishment of mangrove harvesting blocks, harvesting mechanisms and community-ecotourism.

2.2. Project Setting

The focus of the GEF Blue Forests Project small-scale intervention entitled ‘Mozambique Blue Forest Project’ is the application of blue forests methodologies and approaches for valuing carbon and other ecosystem services (ES). The intervention aims to improve the understanding of ES and carbon sequestration for mangrove ecosystems in Mozambique, and, to develop an improved ecosystem management founded on that understanding.

The overall objective of Component 1 is the application of methodologies and approaches for carbon accounting and ecosystem service valuation in blue forests ecosystems to provide an evidence-based experience that supports replication, up-scaling and international adoption of the blue forests concept.

The project outcomes associated with intervention are: 1) an improved understanding of ecosystem services carbon sequestration, storage, avoided emissions and management in mangrove ecosystems covering 25,500 ha; and 2) improved ecosystem management as a result of the application of methodologies in the same site covering 25,500 ha.

The project outcomes will be fulfilled through an increased understanding and capacity in mangrove ecosystem service valuation at the local and national scale, an increased understanding of management practices that promote the preservation of mangrove ecosystem services, and the incorporation of carbon and other ecosystem services into climate and mangrove relevant policy and management at the national scale.

2.3. Ecosystem Services Assessment

The ecosystem services assessment was led by António Mubango Hogueane, Professor of Physical Oceanography and Chair of Marine Sciences and Oceanography and integrated a multidisciplinary team composed by oceanographers, GIS, ecologists, foresters and socio-economic experts from the Superior School of Marine and Coastal Sciences in partnership with WWF MCO. The study comprised various stages of research process including scoping, data sharing, reviewing, outreach and dissemination, workshops and field visits were organized with the aim to engage policy makers, practitioners and local communities maximizing incorporation of their knowledge and visions. This process was facilitated by the Provincial Directorates of Environment and Provincial Directorates of Science, Technology, Higher Education and Vocational Training. The study commenced in September 2016 and ended in April 2017.

2.4. Mangrove ecological value – global perspective

Mangroves are marine wetland vegetation that grows in coastal saline or brackish water. They are adapted to wet soils, saline habitats and periodic tidal inundation. Therefore are salt tolerant trees, also called halophytes and are adapted to life in harsh coastal conditions such as waves, high salt and temperature gradients (Alongi, 2002). Mangrove trees have aerial roots, exposed to the surface, which obstruct the water circulation and thus foster sedimentation. Because of this property, mangroves are often referred as "land-builders" (Hatcher *et al.*, 1989). They are associated with mangrove swamps which may be connected by a single or a limited number of tidal inlets either to an estuary, lagoon and bay or directly to the coastal continental shelf. These tidal inlets, responsible for the drainage of the swamps, are also called mangrove creeks and act as nursery and breeding grounds for important fishery species. The swamps are regularly influenced and disturbed by seasonal freshwater and semidiurnal tidal flooding so, the water masses of the mangroves may be brackish. The salinity has large time scale variability: diurnal or semidiurnal as well as bi-weekly because of the tides, and annual due to the change from dry to rainy seasons. The swamp is, in general, shallow and may remain dry for several hours during low water hence, prone to high temperature diurnal amplitudes. The upper reach of the swamp may only be flooded during the highest spring tides. There may be a sill at the mouth of the mangrove creek. This may be a result of sand movement, due to the action of the waves along the beach. The height of the sill may determine the extent to which, and the time span that, the mangrove may be flooded (Hogueane *et al.*, 1999).

According to Giri *et al.* (2011) the worldwide total area of mangroves, as estimated in the year 2000, was 137,760 km², distributed in tropical and subtropical coastal regions, with most of mangroves found between 5° N and 5° S latitude. Asia has the largest amount (42%) of the world's mangroves, followed by Africa (21%), North/Central America (15%), Oceania (12%) and South America (11%) (Giri, 2011). Fatoyinbo and Simard (2013) using Land Sat images estimated the total mangrove of Africa to be 25,960 km² during the period 1999-2002. Mozambique with an estimated mangrove area of 2,677.27 km², is in the top 20 mangrove holding countries as per estimates in 2014 (Hamilton, *et al.*(2016). There are about 110 species distributed in about 17 main genera (Giri *et al.*, 2011), where the common genera are: *Avicennia*, *Rhizophora*, *Bruguiera*, *Ceriops*, *Sonneratia* and *Xylocarpus*. The African continent holds 17 species of mangroves. The highest diversity of mangrove species is found in the Indo-Malesian region, with about 48 mangrove species (Duke *et al.*, 1998).

Productivity & Nutrient Flux

Mangrove trees are a primary biological component of the coastal environment. They extract phosphorus and nitrogen from the sediments and synthesize carbon. By the fall of their leaves, branches and trunks, and by subsequent decomposition they provide, to the adjacent seas, dissolved and particulate organic matter. In doing so, they contribute to the recycling on nutrients (Kathiresan and Bingham, 2001). Mangrove forests are among the world's most highly productive ecosystems, with gross primary production estimated at 3 – 24 g C m⁻² day⁻¹, and net production estimated at 1 – 12 g C m⁻² day⁻¹ (Lugo and Snedaker 1974, Lugo *et al.* 1976). Mangroves accumulate excess nutrients such as nitrogen and phosphorus and pollutants such as heavy metals and trace elements that are deposited into estuarine waters from terrestrial sources, acting as nutrient “sinks” for these materials. Hence they contribute to clean the environment. Further, mangrove roots, epiphytic algae, bacteria and other microorganisms, as well a wide variety of invertebrates take up and sequester nutrients in their tissues, often for long periods of time. In addition, mangroves act as sources for carbon, nitrogen, and other elements as living material dies and is decomposed into dissolved, particulate and gaseous forms. Leaf litter, including leaves, twigs, propagules, flowers, small braches and insect refuse, is a major nutrient source in mangrove systems (Odum 1970). Generally, leaf litter is composed of approximately 68 – 86 % leaves, 3 – 15 % twigs, and 8 – 21 % miscellaneous material (Pool *et al.* 1975). Once fallen, leaves and twigs decompose fairly rapidly into dissolved nutrients. Through tidal flushing the nutrients are distributed and fertilize adjacent coastal waters (Hoguane *et al.*, 2012).

Climate change mitigation and adaptation

Mangroves have the ability to sequester carbon from the atmosphere and serve as both a source and repository for nutrients and sediments for other inshore marine habitats, such as seagrass beds and coral reefs. Hence, reducing greenhouse gases in the atmosphere and so, mitigate the effect of global climate change. Storage of carbon in mangroves takes place through accumulation in living biomass and through burial in sediment deposits, with living biomass typically ranging between 100-400 tonnes/ha, and significant quantities of organic matter being stored in the sediments. Mangroves are said to contribute 50% of carbon burial in marine sediments, CO₂ sinks, about 13.5 Gt year⁻¹, which correspond to about 1% of the world's forests carbon sequestration (Alongi, 2014). The average world carbon burial rate for mangrove was estimated at 2.26 tC ha⁻¹ yr⁻¹ (McLeod, 2011). In addition, their canopies dissipate wave energy and high burial and sedimentation rates raise the floor, buffering the impacts of rising sea level and wave action that are associated with climate change (Duarte, 2013).

Ecological Role of Mangroves

Mangrove swamps are important nursery areas for several commercial fish and crustacean species, and they give, further, a foothold for other animals. Many species make use of mangrove areas for foraging, roosting, spawning, breeding, and other activities. For instance, the juvenile of the Penaeid shrimps develop in mangrove swamps. Both the availability of food and protection in the mangrove swamps are the cause for attraction of juvenile fish and crustacean species (Hatcher *et al.*, 1989). The turbidity in mangrove swamps create a suitable sheltering environment against predators which in turn increases the survival rate of the larvae and juveniles, as explained by several authors (Hoguane *et al.*, 2012; Ayub, 2010; Loneragan, 1999). Odum *et al.* (1982) on studying *The ecology of the*

mangroves of south Florida reported 220 fish species, 24 reptile species, 18 mammal species, and 181 bird species associated with mangrove habitat.

Large artisanal and commercial fisheries are associated with mangrove forests. Kampetsky (1985) quoted by Hatcher *et al.* (1989) has estimated that the average yield of fish, shrimps and crabs from the mangrove associated swamps and estuaries is about 9 tonnes per square kilometer per year. Pauly and Ingles (1986), quoted by Hatcher *et al.* (1989) estimated catch of about 14 tonnes of prawns per square kilometer of mangrove forest each year. So, a healthy mangrove environment could be an indication of high production of coastal fish resources. De Graaf & Xuan (1997) showed some correlation between fish catches and mangroves in Vietnam. They considered that 1 hectare of mangrove supported about 500 kg/year of marine catch, but the issues were complicated by significant changes in fishing effort.

Mangroves are important to local communities for they provide timber and charcoal used in domestic and industrial events, and also because they are associated with large artisanal and coastal fisheries that are the base for their subsistence. Table 2.1 presents relative values of the mangrove production in terms of fish, aquaculture and charcoal (Hatcher *et al.* (1989). The data indicate that in Malaysia and Thailand, sustained yield management of mangrove forests for fishery and charcoal produced similar revenue to that achieved by aquaculture ventures in or near mangroves. In both the Philippines and Burma, one of either the fishery or charcoal production had a similar value to aquaculture. Research by Barbier (2007) concluded that the economic annual value of mangrove forest (by adding the values of collected wood and non-wood forest products, fishery, nursery and coastal protection against storms) was US\$12,392 ha⁻¹ yr⁻¹. Chevallier (2013) quoting Ten Brink, P (2011) indicated that the habitat–fishery linkages worth US\$171 per hectare per year. Recent studies of mangrove ecosystem value as fisheries nursery by Hutchison *et al.* (2015) indicated that inshore fish catch of 20.9–1,195 kg ha⁻¹ yr⁻¹, with average of 120.1 kg ha⁻¹ yr⁻¹, corresponding to 0.2–2,164.1 US\$ ha⁻¹ yr⁻¹, with average 106.1 US\$ ha⁻¹ yr⁻¹; inshore crab catch of 4.1–232.8 kg ha⁻¹ yr⁻¹, with average 45.1 kg ha⁻¹ yr⁻¹, corresponding to 423.4 US\$ ha⁻¹ yr⁻¹; offshore prawns catch of 9.3–180.1 kg ha⁻¹ yr⁻¹, with average of 122.3 kg ha⁻¹ yr⁻¹, corresponding to 24.3–1,394 US\$ ha⁻¹ yr⁻¹. Chevallier (2013) quoting the 2010 edition of the *World Mangrove Atlas* indicated that the estimated overall economic value of the mangrove ecosystem services were between US\$2,000 and US\$9,000 per hectare per year, greater than those could be generated by aquaculture, agriculture, insensitive tourism and urban development. Conversely, rehabilitation of degraded mangrove site could cost about \$8,240 per hectare in the first year, followed by annual maintenance and protection of seedlings costs of \$118 per hectare. Therefore, mangroves seem to yield more to man when preserved than when claimed for any other use.

Table 2.1. Relative monetary value (US\$.ha⁻¹ yr⁻¹) of fish, aquaculture, and sustained-yield forest production (mainly charcoal) in some mangrove systems in the mid 1980s, after Hatcher *et al.* (1989).

Country	Catch/Fish	Aquaculture	Forest Production
Bangladesh	21	346	55
Brazil	769	-	-
Burma	-	320-640	236
Indonesia	-	684	-
Malaysia	1375-2773	3200	203-290
Philippines	561	800	-
Thailand		1600	227

Coastal protection

Although mangrove communities develop best in the absence of strong currents or wave action, once they are settled they prevent coastal erosion and protect and shelter the coast against extreme weather events, such as storm winds and floods, as well as tsunamis, and absorb and disperse tidal surges associated with these events. In this way they contribute to coastal protection. Because of this property, mangroves are often referred as "land-builders" (Hatcher *et al.*, 1989). It has been said that the hurricane and tidal wave which claimed several hundred thousand lives and coastal infrastructures in Bangladesh might not have been so destructive if thousands of hectares of mangrove forests in the area had not been replaced by rice paddies (Hatcher *et al.* 1989). Hirashi and Harada (2003) indicated that a mangrove forest density of 30 trees per 100 m² with a depth of 100 m can reduce the destructive force of a tsunami by up to 90% and reduce wave height by as much as 66% over 100 meters of forest. Chevallier (2013) quoting Ten Brink, P. (2011) indicated that the storm protection by mangrove worth US\$1,879 per hectare per year. In addition to economic value, mangroves also have great cultural significance for communities. Badola *et al.* (2003) valued the storm protection function of mangroves in India by cyclone using damage avoided method. They assessed the damage to houses, livestock, fisheries, trees and other assets caused by cyclones and storms and they result ranged from US\$1,454.13 to US\$6,918.62. Recognizing the importance of mangroves, there have been projects for mangrove reforestation, where they are degraded and of conservation and protection where they exist undertaken by government, academia, NGO's and CBO's organizations, worldwide.

Mangroves under threat

Coastal habitats across the world are under heavy population and development pressures, and are subjected to frequent storms. The continued decline of the forests is caused by conversion to agriculture, aquaculture, tourism, urban development and overexploitation (Alongi, 2002; Giri *et al.*, 2008). About 35% of mangroves were lost from 1980 to 2000 (MA, 2005), and the forests have been declining at a faster rate than inland tropical forests and coral reefs (Duke *et al.*, 2007). Relative sea-level rise could be the greatest threat to mangroves (Gilman *et al.*, 2008). Predictions suggest that

30–40% of coastal wetlands (IPCC, 2007) and 100% of mangrove forests (Duke et al., 2007) could be lost in the next 100 years if the present rate of loss continues. As a consequence, important ecosystem goods and services (e.g. natural barrier, carbon sequestration, biodiversity) provided by mangrove forests will be diminished or lost (Duke et al., 2007). Mangrove forests are among of the most productive and biologically important ecosystems of the world because they provide important and unique ecosystem goods and services to human society and coastal and marine systems. The forests help stabilize shorelines and reduce the devastating impact of natural disasters such as tsunamis and hurricanes. They also provide breeding and nursing grounds for marine and pelagic species, and food, medicine, fuel and building materials for local communities. Mangroves, including associated soils, could sequester approximately 22.8 million metric tons of carbon each year. Covering only 0.1% of the earth's continental surface, the forests account for 11% of the total input of terrestrial carbon into the ocean (Jennerjahn & Ittekkot, 2002) and 10% of the terrestrial Dissolved Organic Carbon (DOC) exported to the ocean (Dittmar et al., 2006). The rapid disappearance and degradation of mangroves could have negative consequences for transfer of materials into the marine systems and influence the atmospheric composition and climate.

2.5. Mangrove ecological value – national overview

According to Barbosa *et al.* (2001) the mangroves forest extension in Mozambique was estimated at approximately 396 080 hectares. The estimate was based on site visit observations, during a period of 8 years (1972-1990), and on literature review. The highest concentration of mangroves was found in central Mozambique, in the provinces of Sofala and Zambezia, which account to 71% of the total mangroves of Mozambique. There are 9 mangrove species occurring in Mozambique, and the dominant species are as follows: *Avicennia marina*, *Bruguiera gymnorrhiza*, *Ceriops tagal*, *Heritiera littoralis*, *Lumnitzera racemosa*, *Rhizophora mucronata*, *Sonneratia alba*, *Xylocarpus granatum* and *Acrostichum aureum*. Mozambique has the largest diversity of mangroves in the continent (Temilola and Simard, 2013; Spalding *et al.* 1997). The mangroves are distributed along the coast, with higher density in the deltas and estuaries of large rivers, being the Zambezi Delta the largest of all. Bandeira *et al.* (2012) pointed out that the Zambezi River Delta mangrove area, estimated at about 100,000 ha, was the largest mangrove stand in the whole eastern African coast; and with 8 mangrove species, was considered the highest diversity mangrove area. Table 2.2 reviews the evolution of the mangrove area in the whole Mozambican coast as estimated by several authors. Saket and Matusse (1994) using Landsat imagery of the period 1973-1992 estimated the 396,000 ha. Later, Fatoyinbo *et al.* (2008) using the same method for the period 1973-1992 estimated the total mangrove forest cover in Mozambique at 290,900 ha, 27% lower than previous estimates, suggesting mangrove loss. Giri *et al.* (2010) using Landsat imagery (1999-2002) estimated at 318,851 ha. The estimate of 1999-2002, though were 305,400 ha (Fatoyinbo and Simard, 2013), probably suggesting the effectiveness of the awareness campaigns taken by NGO's and management measures undertaken by the government institutions following the establishment of the Ministry of Environment in earlier 90's. The mangrove area in the Zambezi Delta was estimated at 37,034 ha, based in the Landsat imagery from 1994-2013 (Shapiro *et al.*, 2015). Further, they observed that mangrove area in the Zambezi River has been increasing in coverage with a net gain of 3,723 ha (or 10%), from 33,311 ha to 37,034 ha during the period 1994-2013.

Table 2.2. Review of the estimate of mangrove area in Mozambique, according to several authors.

Estimated area (ha)	Year of the estimate	Methodology applied	References
305,400	1999-2002	Landsat imagery (1999-2002)	Fatoyinbo and Simard (2013)
318,851	1999-2002	Landsat imagery (1999-2002)	Giri <i>et al.</i> (2010)
290,900	1973-1992	Landsat imagery (1973-1992)	Fatoyinbo <i>at al.</i> (2008)
396,000	1973-1992	Landsat imagery (1973-1992)	Saket and Matusse (1994)

Mangroves and climate mitigation

Bandeira *et al.* (2012) indicated that Zambezi Delta mangroves sequester high carbon stocks, and so, it is an ideal place for developing Carbon credits initiatives. Shapiro *et al.* (2015) using land cover change assessment method estimated the mangrove ecosystem carbon stocks in the Zambezi Delta, and concluded that the mangrove ecosystem in the Delta acts as a large carbon sink, with an estimated net increase of 691,032 Mg of carbon during the period 2000–2013. Stringer *et al.* (2015) estimated the total amount of carbon stock in the Zambezi Delta mangrove system at 14.3 Gg.

Mangrove ecological value

It is generally recognized that mangroves of Mozambique, and in particular those of the Zambezi Delta provide suitable living habitat, nursery ground and shelter to several species of fish and shrimp, including those of economic importance, hence, supporting the most productive fish and shrimp fisheries of the country, the Sofala Bank, one of the most important fishing grounds of the eastern African region (WWF, 2016). There have been seldom referenced studies relating the fisheries production to mangroves. The annual shrimp catch in the entire Sofala Bank is of the order 6,000-10,000 t and the annual fish catches are of the order of 50,000-100,000 t (WWF, 2016; IIP, 2014; Brinca *et al.*, 1983). Gammelsrød (1992) in his work stated that penaeid shrimp spawn in open sea but they spend their earlier stage of life up to juvenile in the sheltered mangrove swamps and estuary. This statement can be understood as recognition of the ecological role of mangroves. Mangroves are also important fishing grounds for several species of fish, penaeid shrimp, and the mangrove crab *Scylla serrata* (Macia *et al.* 2014; Piatek, M.A., 1981). Nunes and Ghermandi (2015) undertook studies, commissioned by WWF and CORDIO, for understanding and valuing marine ecosystem services in the Northern Mozambique Channel. The study covered Mozambique and Madagascar and ecosystems of mangroves, seas, coral reefs and coastal wetlands and covered the following categories provisioning (fisheries), cultural (coastal tourism) and regulating (coastal erosion prevention and carbon sequestration). More information about the role of mangroves in fisheries availability in Mozambique is presented in Chapter 3, below.

Mangrove uses

In Mozambique mangrove are harvested for building materials, firewood, fencing, fish traps and for medicinal purposes. Ecologically, mangroves play an important role as nursery and feeding grounds for many important commercial fish and for medicine purposes. Siteo *et al.* (1991) indicated that in Maputo bay about 9 234 metric tons are harvested annually for building poles. De Boer (2002)

quoting Hatton (1995) indicated that an area of 2,000 ha of mangroves was providing 9,200 tons of firewood annually in Inhaca island, around Maputo Bay, Mozambique. Bandeira *et al.* (2012) indicated that the main mangrove products in the Zambezi delta are wood (for housing, boat construction and production of various domestic utensils) and poles, and that non woody uses were medicinal and extraction of dye. They conducted a survey based on interviews, and found that 62.5% of the interviewed people preferred *Ceriops tagal*, 31.25% preferred *Avicennia marina* and *Ceriops tagal* and 6.25% preferred *Ceriops tagal* and *Xylocarpus granatum*. Barbosa *et al.* (2001) presented the use of mangroves in Mozambique by species as follows: the species *Bruguiera gymnorrhiza*, *Ceriops tagal*, *Sonneratia alba*, *Rhizophora mucronata* and *Lumnitzera racemosa* are used for poles for building houses; the species *Bruguiera gymnorrhiza*, *Ceriops tagal*, *Lumnitzera racemosa*, *Rhizophora mucronata*, *Sonneratia alba* and *Xylocarpus granatum* are used for firewood; *Ceriops tagal* is used for charcoal production; the species *Avicennia marina*, *Ceriops tagal*, *Xylocarpus granatum* are used for boat building; *Xylocarpus granatum* has medicinal property; the fruits of *Phoenix reclinata* are edible and used to make an alcoholic beverage.

Mangroves under threat

Mangroves in Mozambique, similarly to mangroves in other parts of the world, are under threat both from anthropogenic as well as natural forcing. Human impacts are generally limited to extraction of wood and poles for building houses, boat construction and production of domestic utensils (Shapiro *et al.*, 2015). Barbosa *et al.* (2001) and further seconded by WWF (2016) identified the major threats to mangroves in Mozambique as follows: (i) overexploitation for firewood, charcoal and poles, fish traps and furniture (WWF, 2016); (ii) clearance of mangroves for agriculture (mainly for rice fields) and salt production; (iii) pollution and (iv) decreased flow of freshwater to mangroves caused by dams (Saket and Matusse, 1994, Doddema, 1997, Doddema and Manjate, 2000). Saket and Matusse (1994) indicated that people immigration into coastal areas and the resulting pressure led to clearance of mangrove areas for human settlement. Barbosa *et al.* (2001) pointed out that in northern Mozambique about 50% of the mangroves were transformed into salt pans. Doddema (1997) indicated that management of the hydroelectric dam in the Zambezi River resulted in a reduced flow of freshwater, which in turn caused the shrinking of mangrove areas and accelerated erosion. Bandeira *et al.* (2012) also reiterated that the changes in river flow regimen caused by the dam was causing downstream sediment deficit, which in turn was causing erosion and death of mangrove in the Zambezi River Delta. Barbosa *et al.* (2001) estimated the mangrove deforestation rate in Mozambique at $1\ 821\ \text{ha}^{-1}\ \text{yr}^{-1}$, with the highest value around large cities like Maputo, with 15.2% and Beira, with 4.9%, and the lowest values around small cities such as Inhambane, with 1.2% deforestation rate. De Boer (2002), using aerial photographs (1:10.000) of the period 1958–1991 estimated the deforestation rate of 8% for Maputo Bay.

2.6. Mangrove ecological value - Economic assessment approaches

Many of the ecosystem services provided by mangroves that contribute to human wellbeing, have the characteristics of 'public goods' and are non-marketable such that it does not encourage private investment for their conservation. Consequently, mangroves are generally undervalued in both private and public decision-making relating to their use, conservation and restoration. Thus, the economic value of natural products and ecosystem services generated by mangrove forests is generally underestimated (Saenger *et al.*, 1983; Hamilton and Snedaker, 1984; Hamilton *et al.*, 1989; Barbier, 1994). The lack of understanding of, and information on, the values of mangrove ecosystem

services has generally led to their omission in public decision making (Brander, 2012). Without information on the economic value of mangrove ecosystem services that can be compared directly against the economic value of alternative public investments, the importance of mangroves as natural capital tends to be ignored. A number of studies have developed and applied methods to calculate the monetary value of mangroves (Ramdial, 1975; Ahmad, 1984; Barbier, 1994; Bann, 1998), and in general the studies indicated that the services provided by mangrove have positive economic value. Figure 2.1. presents the framework for the Evaluation of mangrove ecosystem services, considering both its use values and non-use values, direct and indirect use. The following cost-based methods criteria are commonly used:

- **Avoided cost** - The expected damages avoided by maintaining the ecosystems' protective functions, such as the costs of replacing infrastructure, or the losses to productive values of land;
- **Replacement cost** - The defensive expenditures required replacing or restoring the protective function of the ecosystem, such as the costs of constructing and maintaining sea wall or windbreak infrastructure;
- **Relocation** - The costs of relocating communities if protective functions are lost.
- **Factor income:** services provided for the enhancement of incomes (e.g. improved water quality increases the commercial take of fishery and improves the income of fishers).

The detailed economic valuation techniques frequently used are as follows:

- Replacement costs: Even where mangrove goods and services have no market themselves, they often have alternatives or substitutes that can be bought and sold. These replacement costs can be used as a proxy for mangrove resource and ecosystem values, although usually represent only partial estimates, or under-estimates.
- Effects on production: Other economic processes often rely on mangrove resources as inputs, or on the essential life support provided by wetland services. Where they have a market, it is possible to look at the contribution of mangrove goods and services to the output or income of these wider production and consumption opportunities in order to assess their value.
- Damage costs avoided: The reduction or loss of mangrove goods and services frequently incurs costs in terms of damage to, or reduction of, other economic activities. These damage costs avoided can be taken to represent the economic losses foregone by conserving mangroves.
- Mitigative or avertive expenditures: It is almost always necessary to take action to mitigate or avert the negative effects of the loss of mangrove goods and services, so as to avoid economic damage. These mitigative or avertive costs can be used as indicators of the value of conserving mangroves in terms of expenditures avoided.
- Hedonic pricing: Hedonic methods look at the differentials in property prices and wages between locations and, isolate the proportion of this difference that can be ascribed to the existence or quality of mangrove goods and services.

- Travel costs: Mangrove forests typically hold a high value as a recreational resource or destination. These travel costs reflect the value that people place on leisure, recreational or tourism aspects of mangrove forests.
- Contingent valuation: Contingent valuation techniques infer the value that people place on wetland goods and services by asking them their willingness to pay for them (or willingness to accept compensation for their loss) under the hypothetical scenario that they would be available for purchase.
- Non-market valuation: which will be measured using travel cost (TC), contingent valuation (CV), or hedonic pricing (HP) methods.

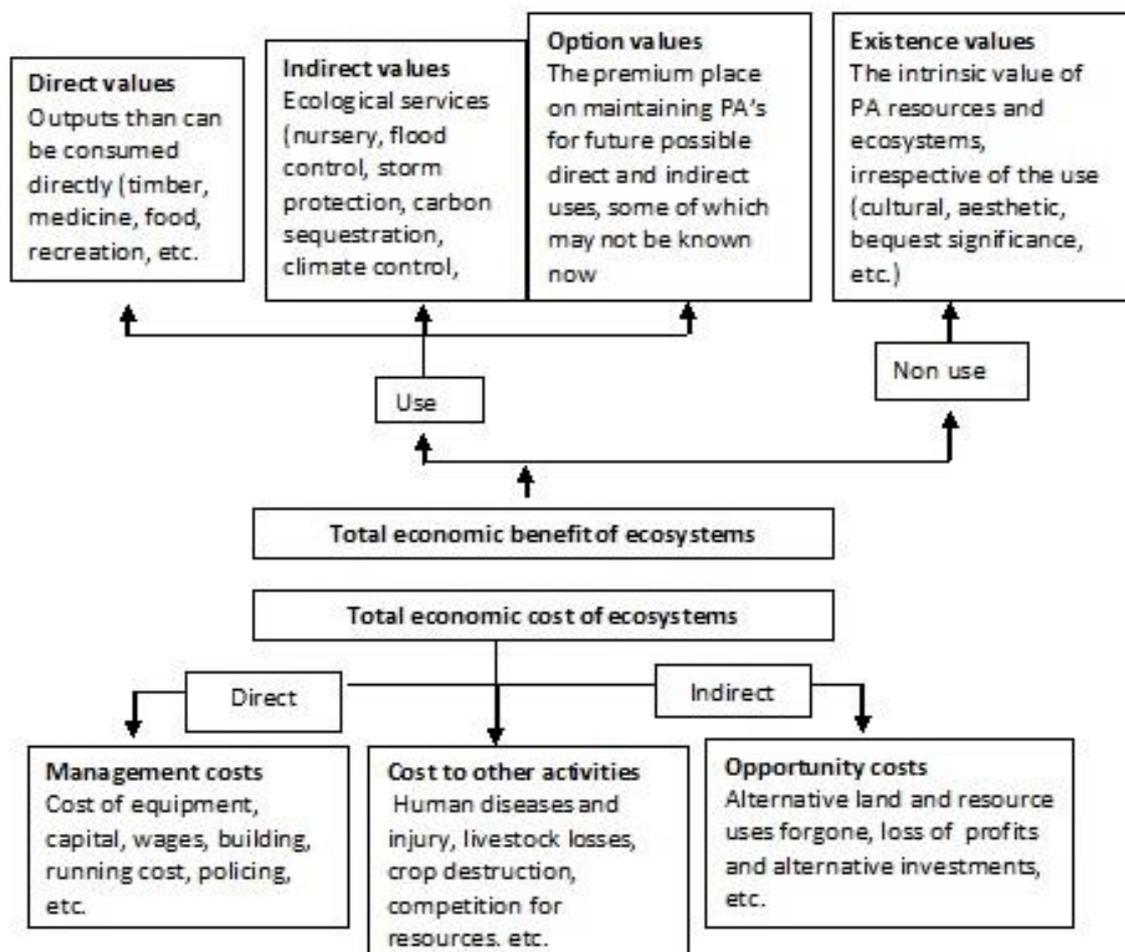


Figure 2.1. Proposed framework to estimate the total economic value of the mangrove Ecosystems in Zambezi Delta.

3. General Bio-physical description of the Zambezi Delta

3.1. General description

The Zambezi Delta is where the Zambezi River enters the Indian Ocean. It is a triangular shaped alluvial plane, spanning from about 120 km long, from its inland, near the confluence of the Zambezi and Shire Rivers, to the main Zambezi River mouth and about 200 km along the Indian Ocean coastline from the Cuacua River outlet near Quelimane, south to the Zuni River outlet. At the latitudes 18° 30'S and 19° 00'S and Longitudes 35° 40'E and 36° 30'E. It covers an area of approximately 12,000 km² (Figure 3.1). It has several branches in an area of about 8,000 km², being the Chinde and Cuama the most significant branches. These branches are navigable and used to transport coal, sugar, and agricultural products from upstream regions for trading with other parts of the country, for export, and transport fish and mangrove products upstream. The Zambezi river plays an important role in the transport of people and goods, and so in trade from neighboring countries and overseas.

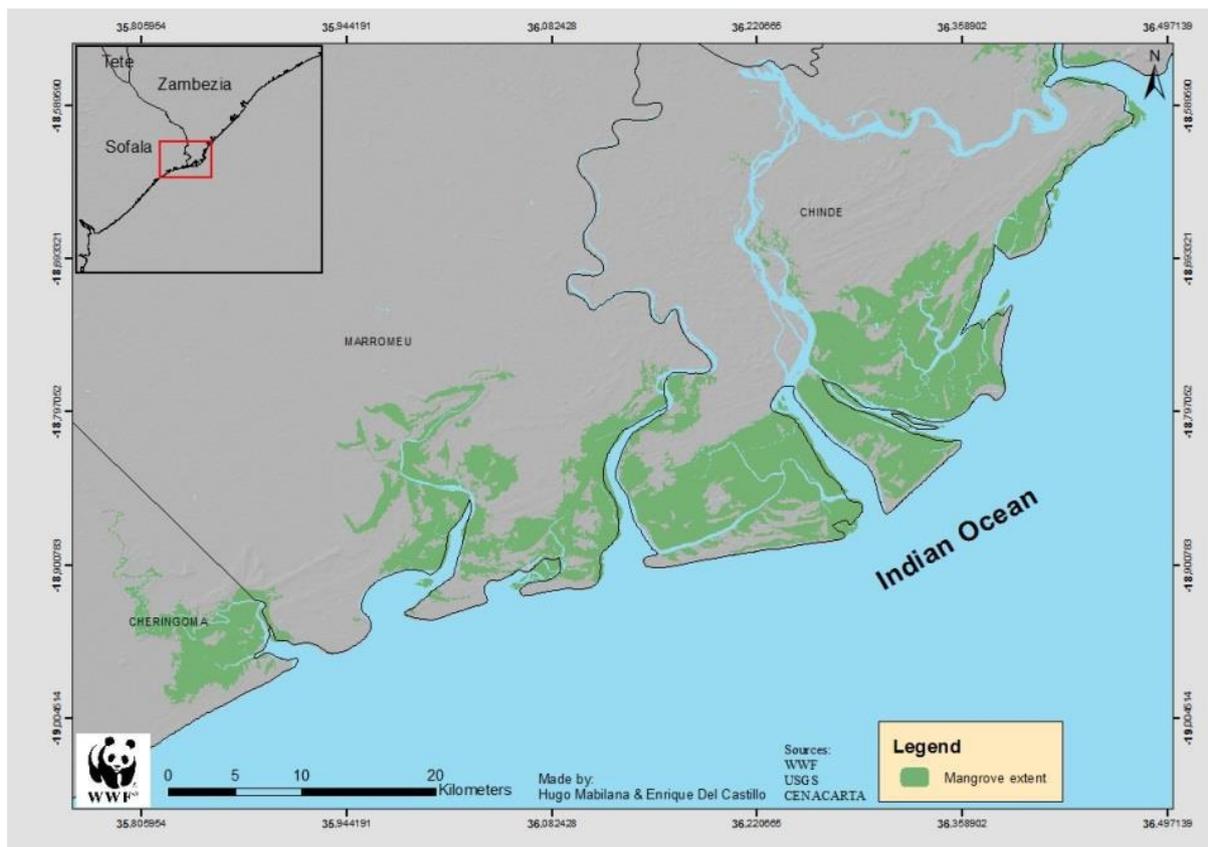


Figure 3.1. Location map of the Zambezi Delta, Mozambique. © WWF.

3.2. Hydrology and climate

According to the classification of Köppen, the climate is predominately tropical rain Savannah (B_{Ww}) with two distinct seasons: summer and winter, and rains mainly during the summer (MICOA, 1998). The prevailing winds are SE Trade, with moderate strength (Table 3.1). Cyclones occur regularly in the delta at the rate of about 3 to 4 per year, for the past 50 years (Hoguane, 2007). Most of these cyclones are of low or moderate strength.

Table 3.1. Winds in the vicinity of the Zambezi Delta as observed during 1964/72 (MICOA, 1998).

Wind force (km/h)	N° of Obs.	Frequency (%)
< 10.0	1917	25.56
10.0 – 14.9	1894	25.25
15.0 – 19.9	1658	22.11
20.0 – 24.9	1096	14.61
25.0 – 29.9	513	6.84
30.0 – 34.9	245	3.27
35.0 – 39.9	112	1.49
40.0 – 44.9	44	0.59
45.0 – 49.9	17	0.23
50.0 – 54.9	3	0.04
> 55	1	0.01
TOTAL	7500	100.00

Zambezi River is the largest river in East and Southern Africa. The average annual discharge is about 140 km³ (Sætre and Jorge da Silva, 1982). The river is regulated by two main hydroelectric dams, the Kariba, with capacity of generating 1,626 megawatts, in Zimbabwe and the Cahora Bassa, with capacity of generating 2,075 megawatts, in Mozambique. Cahora Bassa is the largest dam with storage capacity of 55.8 km³ (Rendel *et al.* 1980) and it has been operational since 1974. The maximum flows at the hydrological station over the Dona Ana Bridge in Tete were mostly over 10,000 m³ s⁻¹ before the regulation, and dropped to about 5,000 m³ s⁻¹ after the regulation. Figure 3.2 shows time series of the annual maximums of the monthly average flows of Zambezi, observed during the period 1940-1999. Before the regulation (i.e. before 1974), the maximum flows were mostly over 10,000 m³ s⁻¹. After the regulation, the maximum flows were mostly below 5,000 m³ s⁻¹, apart from the high observed in 1978, thought to be due to an unexpected release from Kariba Dam, known as “Kariba flood emergency” (Hoguane, 1997). The low flows observed after the regulation could be attributed to the regulation as well as to the drought that affected the whole Southern Africa in 1980’s.

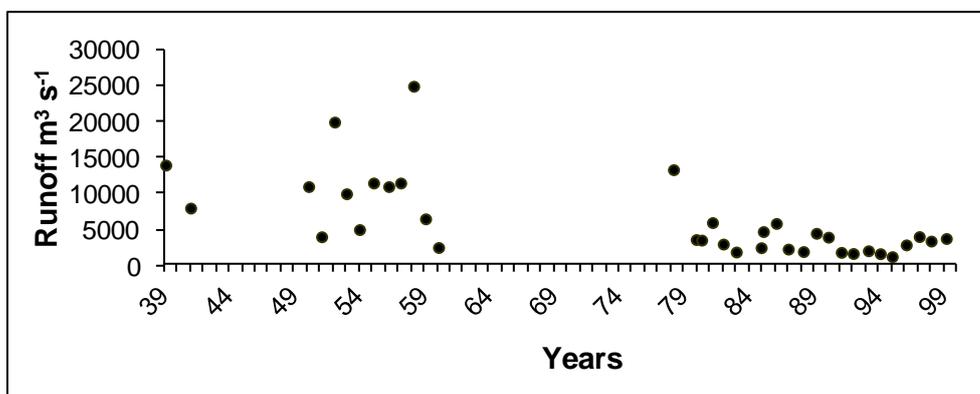


Figure 3.2. Annual maximum runoff of Zambezi River observed at Tete runoff gauge station.

The Zambezi river runoff is said to have positive influence in fisheries production in the entire Sofala Bank. It influences the fisheries through three major processes. Firstly, is the availability and distribution of nutrients, necessary for primary production/food supply of particular importance, during the flood season. Secondly, is the availability of a suitable current system to enable the shoreward transport of eggs and larvae, during the dry season (Gammelsrød, 1992). Thirdly, it creates favorable sheltering environment to protect the larvae and juveniles against the predators and so increasing the survival rate of the fisheries species (Hoguane and Armando, 2015; and Hoguane *et al.*, 2012).

However, the hydroelectric dams are said to have negative impact on the ecology, as they reduce the flood runoff during the wet season to keep water in the reservoir, resulting in a reduced wet season runoff. On the other hand, since they should produce electricity throughout the year, including in the dry season as they allow increased runoff during the dry season than it should be naturally. Gammelsrød (1992) found a positive correlation between the shrimp production in Sofala Bank and the Zambezi runoff during the flood season, which is a clear evidence that an increase in the discharge during that period may enhance the shrimp production, and found a negative relationship between the catch and the dry season runoff, though weaker, it indicates that the runoff should be kept at minimum during the dry season in other to enhance the shrimp production.

Figure 3.3 shows the mean monthly average of the Zambezi discharge, before the regulation (13 years) and after the regulation (16 years). The anomalous years, prior to the regulation (1974) and the super flood year (1978) were excluded from the computation. The result clearly shows how the natural seasonal pattern was affected by the dam. The flood season runoff was reduced by about 40% and the dry season runoff was increased by about the same amount, a situation believed to have a negative impact in the shrimp production in the Sofala Bank.

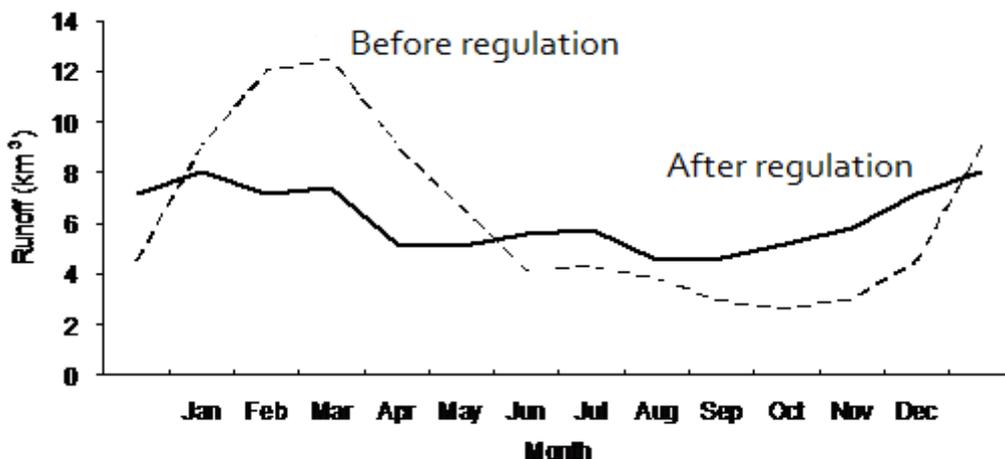


Figure 3.3. Seasonal variation of the Zambezi runoff: before (dashed line) and after (thick line) the regulation.

The Tides in the Delta are semidiurnal with the range varying between 1 m and 5 m during de neap

and spring tides, respectively (Gammelsrød, T. and Hogueane, 1996; Sætre and Jorge da Silva, 1982). Tidal currents in the coastal waters adjacent to the Delta are oriented along NE-SW direction, with speed ranging from 20 to 230 cm s⁻¹. The strongest currents are observed during the spring and during the flood tides. The prevailing waves near the Delta are from South and from SE, with a period of 16 seconds, and most of them have between 1 m and 2 m significant wave height (Table 3.2). Storms occur with a frequency of 1 in every 2.5-5 years.

Table 3.2. Waves in the vicinity of the Zambezi Delta as observed during 1964/72 (MICOA, 1998).

Height (m)	N° of Obs.	Percentage
< 1.00	812	38.39
1.00 – 1.49	921	43.55
1.50 – 1.99	318	15.03
2.00 – 2.49	55	2.60
2.50 – 2.99	8	0.38
3.00 – 3.49	1	0.05
> 3.50	0	0.00
TOTAL	2155	100.00

The ocean circulation off Zambezi Delta is characterized by NE current, following along the coast towards the north (Sætre e Jorge da Silva, 1982). Occasionally it flows south, presumably due to wind forcing.

The oceanographic survey conducted in the delta indicated the dominance of freshwater. Figure 3.4. presents the longitudinal salinity profile of the Delta in October 2016. The maximum salinity recorded was less than 18 psu. The salinity dropped down to 5 at less than 5 km upstream. The water column is mixed with a mild salt wedge of less than 4 m upstream. The predominance of freshwater in the Delta mouth is particularly worrying considering the fact that the observations took place at the tail end of the dry season, where in a normal condition the marine water was expected to register the maximum extension upstream. This shows the effect of the hydroelectric dam which continues to allow huge amounts of water through, even during the dry season, for electricity production. The excess fresh water would have detrimental impact on mangroves, as these require some salt water for living. Figure 3.5 presents the longitudinal temperature profile. The water in the estuary is around 27°C. The ocean water is much cooler, with less than 27°C. At the distance about 35 km from the mouth there is a hot water plume at the surface with temperatures above 27°C. This water mass is believed to out well from a shallow tributary.

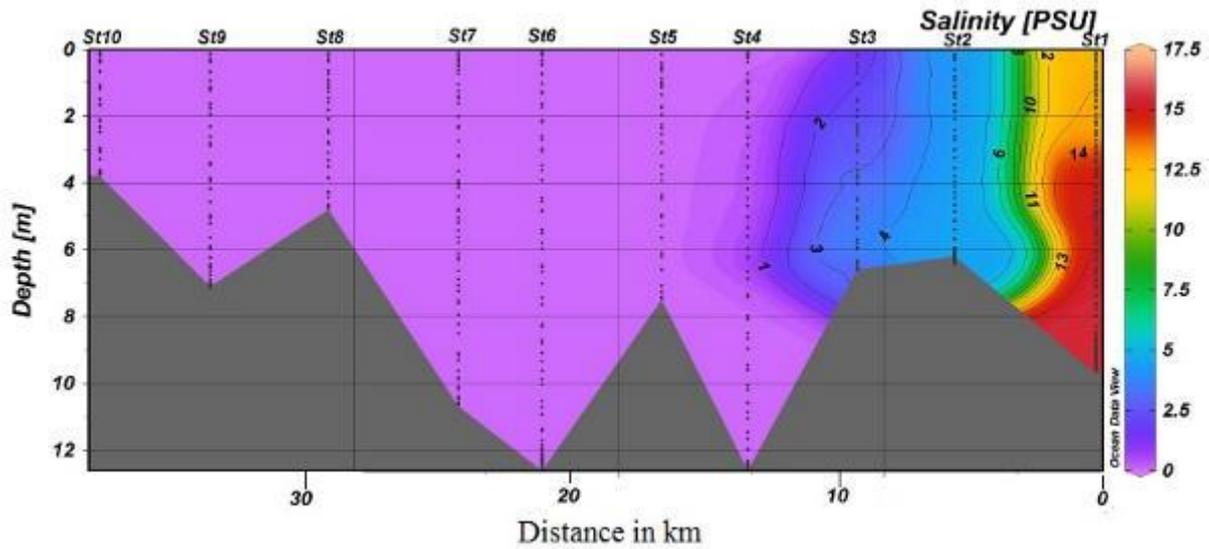


Figure 3.4. Longitudinal salinity profile of the Zambezi delta, during October 2016.

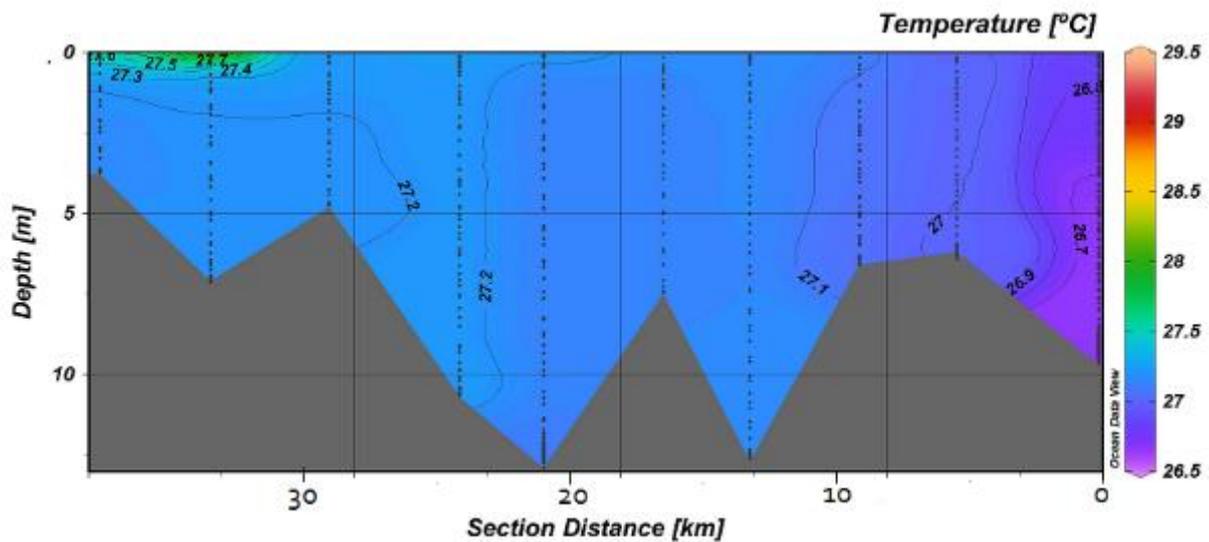


Figure 3.5. Longitudinal temperature profile of the Zambezi delta, during October 2016.

Based on studies of the BSc project (Primeiro, 2015) the flux of sediments, as measured at the Zambezi River mouth in Chinde was 29.9kg s^{-1} and 22.0kg s^{-1} during the ebb and flood tides, respectively, giving a net outflow of sediment of 7.9kg s^{-1} . This net sediment flux is considered low as most of the sediments are expected to be trapped in the dams. The concentration of silicate was about $20\text{-}40\text{ g s}^{-1}$ and of ammonia was $15\text{-}30\text{ g s}^{-1}$, during the low water, suggesting that the river is the source of these nutrients (Figure 3.6).

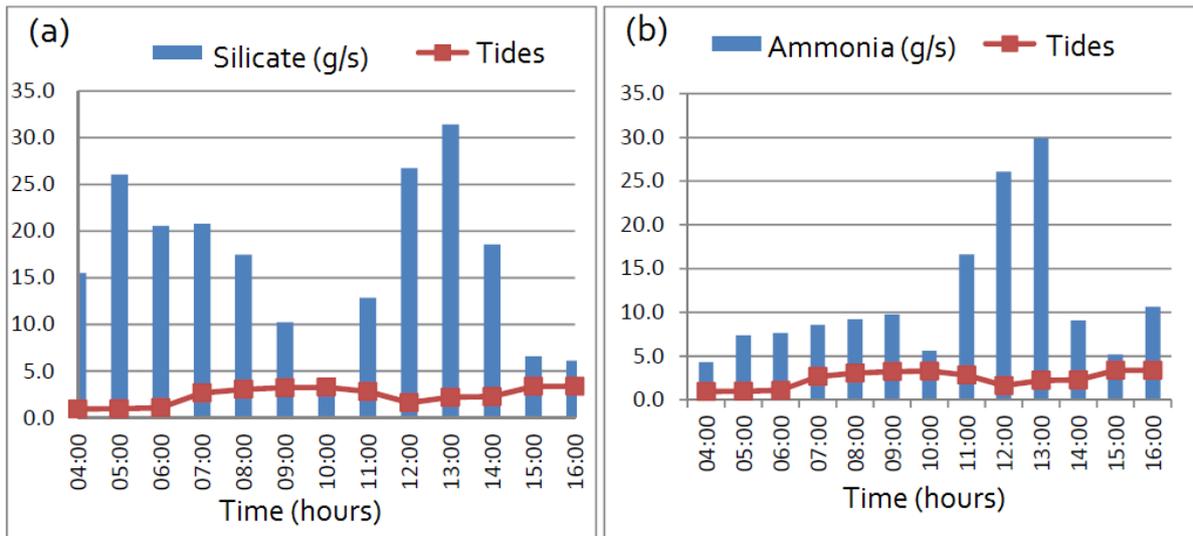


Figure 3.6. Silicate (a) and ammonia (b) concentrations in the mouth of Zambezi river during dry season, July 2014.

3.3. Erosion

There have been reports of slow but chronic erosion in the Delta of Zambezi. The village of Chinde in the northern end of the Delta is one of the most affected areas. Reasons of this persistent erosion are not yet well known, but environmentalists suspect to be the consequence of the reduction of runoff due to the upstream regulation of the Zambezi River (Ronco *et al.* 2010). In fact there are two major dams constructed for production of Electricity: the Cahora Bassa dam, in Mozambique and the Kariba dam, in Zimbabwe, beside several small dams and dikes built to trap water for irrigation, spread along the Zambezi river basin.

The sediment budget in the estuaries is mostly dependent on the input of sediments from the river and from the adjacent seas, and the sediment dynamics is governed by the river runoff and tidal currents. Under normal natural conditions a steady state balance should prevail. This means that there should be no net sediment fluxes in a given portion of the estuary if averaged throughout relatively long periods. However, when the sediment input from the river is reduced, persistent erosion in the delta may occur (Roco *et al.* 2010). The consequences on the coastal ecosystems and infrastructures could be enormous. The Chinde Village, an historical village that used to be an important center of trade between the highland communities (Zimbabwe, Zambia, Malawi up to Zaire) and the Asians before Europeans, is eroding.

3.4. Geology and geomorphology

The region is characterized by flatland of only 3 to 4 meters divided by the river branches and numerous mangrove creeks. The main geological features are: (a) epi- Pleistocene coastal parallel dunes, which are narrow strip wind formed dunes, often not exceeding 15 m high. These are considered the major topographic feature in the region; (b) dune depressions, which are the area between dunes, most of which are connected with humus-clayey tide flood plains, with clay deposits, and dark-humus soils used for agriculture. These soils when dry show shrinkage cracks; (c) tide flood plains, with dark clayey and silty sediments, rich in organic matter and densely colonized by mangroves; (d) flooded alluvial deltaic, constituted by clayey and sandy-clayey deposits of deltaic

features, crossed by a complex hydrological network, justifying the nature of the sediments (fine to very fine, organic matter richness with vegetation detritus); (e) beaches, rich in heavy minerals.

The geomorphology of the Delta is heavily affected by upstream activities and water flows, especially the operation of the Kariba and Cahora Bassa Dams. Though the dams cannot control the extreme floods, are said, however, to weaken the strength of floods and causing the shrinking of the area of floodplain and threatening wetland ecosystems and the associated wildlife in the lower Zambezi, in particular in the Marromeu Ramsar (Davies *et al.*, 2000). Further, the dams are said to reduce the sediment input into the coastal area, by up to 70%, resulting in coastal zone erosion and a reduction of sediment-maintained habitats, including mangroves (Davies, *et al.* 2000). In addition, the Delta is subject to frequent storms that cause geomorphic changes and damage to mangrove tree stands (Beilfuss, *et al.* 2000).

3.5. Soil and vegetation

The region is characterized by alluvial valleys and mangrove swamps with dense mangrove vegetation and soil reach in clay. The Zambezi riverbed is made up of fine sand and mud, moving downstream and forming unstable banks and islands (MICOA, 1998). From the coast towards the inland, the soil is structured as follows: (a) clayey soils of alluvial deposits; (b) sand soils of mananga combined with yellowish sand soils in the interior dunes; (c) sand soils combined with hydromorphic soils; and (d) grey soils from sedimentary limestones. Along the river banks, there are sand sediments of alluvial deposits. And near the ocean there is a combination of marine and alluvial sands, being the clayey soils of estuary origin the dominant sediments, followed by alluvial clayey.

The vegetation is predominantly flooded savannah woodland. It comprises a combination of open grassland, woodlands, mangroves and freshwater swamp vegetation (Beilfuss, *et al.* 2000; Beilfuss and Brown, 2006; World Bank 2010). The coastal zone is characterized by coastal dune vegetation. The savannah woodlands are dominated by Acacia, palms and semi-deciduous forest combined with miombo forest, with *Julbernardia globiflora* and *Androstachys johnsonii* tree species (Wild e Barbosa, 1967). Grasslands include swamp mosaics with areas of phragmites and papyrus. The coastal dunes consist of thickets and woodlands on sandy ridges, with pockets of coconut groves (Beilfuss, *et al.* 2000). Along the river and tidal creeks there is dense mangrove vegetation. According to Smith (1992) and Moll and Werger (1978) the distribution and composition of mangroves are dynamic and directly related to geomorphological changes occurring as a function of coastal erosion and sedimentation processes. The mangrove forest of the Zambezi Delta, according to Shapiro *et al.* (2015), is composed by the eight species found in Mozambique as follows: *Avicennia marina*, *Bruguiera gymnorhiza*, *Ceriops tagal*, *Heritiera littoralis*, *Lumnitzera racemosa*, *Rhizophora mucronata*, *Sonneratia alba* and *Xylocarpus granatum*.

3.6. Wildlife

According to Bento and Beilfuss (2003) the wildlife includes large mammals, such as reedbuck and migrating eland; carnivores such as lion (*Panthera leo*), leopard (*Panthera pardus*), cheetah (*Acinonyx jubatus*), spotted hyena (*Crocuta crocuta*) and side-striped jackal (*Canis adustus*). There are migratory waterbirds including pintails, garganey, African openbill (*Anastomus lamelligerus*), saddle-billed stork (*Ephippiorhynchus senegalensis*), wattled crane (*Bugeranus carunculatus*), and great white pelican (*Pelecanus onocrotalus*). Reptiles include Nile crocodile (*Crocodylus niloticus*), Nile monitor lizard (*Varanus niloticus*) and African rock python (*Python sebae*), the endemic Pungwe worm snake (*Leptotyphlops pungwensis*) and three other snakes that are nearly endemic; floodplain

water snake (*Lycodonomorphus whytei obscuriventris*), dwarf wolf snake (*Lycophidion nanus*) and eyebrow viper (*Proatheris*) and several endemic butterflies.

3.7. Fisheries

Zambezi Delta is located in the central Sofala Bank, the major fisheries ground in Mozambique. The major fisheries comprise shrimp, small pelagic and demersal fish species. According to Brinca and Palha de Sousa (1984) the main shrimp species are of Penaeidae family, being *Penaeus indicus* and *Metapenaeus monoceros* the most abundant species (Saetre e Paula e Silva, 1990). These are shallow water shrimp captured in depth less than 25 m, hence in coastal waters. Further, they spend the larval up to juvenile stage in estuaries and mangrove creeks. In the mangrove creeks there are crabs of specie *Scylla serrata* (Piatek, 1981). The small pelagic fish species include the scads and mackerel, where the main species are *Decapterus russelli* and *Rastrelliger kanagurta* (Brinca et al, 1983), captured in 20 to 90 m depths, sometimes entering the estuaries and mangrove creeks; the anchovy, with the main species *S. punctifer* and *S. heterolobus* and sardines with the main species *Pellona ditchela* and *Thryssa vitrirostris*; the magumba also known as malola, *Hilsa kelee*, and as patanas, *Leiognathus equulus* and *Secutor insidiator*; xaréu malabárico, *Carangoides malabaricus*, and *Ariomma indica*. The demersal fish species includes the species of Lutjanidae family, *Lutjanus bohar*, *L. sanguineus* e *L. gibbus*. The large pelagic fishes include *Scomberomorus commerson* (Saetre and Paula e Silva, 1979).

3.8. Demography

It is estimated that there is about 188,206 people, of which 95,211 are women, representing a proportion of about 50.5%, living in the delta and gaining their livelihood out of the resources in the Delta, or related activities. This population of the Delta is mainly distributed in the Districts of Marromeu, in Sofala Province and Chinde, in Zambezia Province.

3.9. State of mangrove conservation

The Delta has extensive coastal mangroves, estimated to about 37,034 ha, with an increase rate of about 196 ha yr⁻¹, as from assessment carried in 2013 (Shapiro et al., 2015). Assessment made during the present studies, based in satellite images of 2016, gave an estimate of 39,532 ha of mangrove in the delta (Figure 3.7). However, in the present report it was used the figure of 2013, because it was considered reliable and also because the fisheries data used are of 2014. Based on the observation and measurements made in sampled location during the field surveys the following results were obtained:

Mangrove tree density

The old mangrove forests, over 30 years old with tall mangrove trees, had a mangrove tree density of 1550 trees per hectare on average, where about 48% were trees of 10-20 m height and another 48% were trees of 20-30 m height; about 55% were trees with diameter 10-20 cm, about 30% were trees with diameter 30-50 cm, as showed in Table 3.3.

Table 3.3. Density of mangroves trees by height classes per hectare in an old mangrove stand, from present study.

Diameter frequency		Height frequency	
DAP (cm)	Percentage	Height (m)	Percentage
10 - 20	54.8	1-10	3.0
20 - 30	16.1	10-20	48.5
30 - 40	22.6	20-30	48.5
40 - 50	6.5		

In the new mangrove stand (about 4 years old) the density of mangrove trees was about 26,900 trees per hectare on average, where about 95% were trees less than 3 m height; about 58% were trees with diameter 8-20 cm, about 40% were trees with diameter 20-30 cm, as showed in Table 3.4.

Table 3.4. Density of mangroves trees by height classes per hectare in a new mangrove stand, from present study.

Diameter frequency		Height frequency	
DAP (cm)	Percentage	Height (m)	Percentage
8 - 20	58.3	<3	94.8
20 - 30	38.9	3 - 10	3.0
30 - 40	2.8	10 - 20	2.2

Mangrove regeneration

Mangrove regeneration occurs along the beach, along the sand dunes apparently built by waves and storms. The dunes created enable a sheltering environment to fix and germinate the mangrove seeds. On the other hand on the old and dense mangrove stands the rate of forest regeneration is low, about 6.5%. It is low because the old trees block the new and small trees to grow. The rate of forest regeneration in a new mangrove stand is as high as 99%.

3.10. Mangrove use

The mangrove creeks and estuary provide important spawning grounds for riverine and oceanic fish species, and so, nourish both artisanal and semi-industrial fisheries and the prawn fisheries on the Sofala Bank, one of Mozambique's most important sources of export revenue. Further, the mangroves provide goods and services that sustain most of the people living in the Delta. The major mangrove uses are:

- Direct harvesting of mangrove tree products for building material, firewood and charcoal production. This involves mangrove cutting.

- Exploitation and use of resources provided by mangrove ecosystem services. This does not involve mangrove cutting.

Mangrove harvesting

There are few spots of mangrove deforestation, where mangroves are cut for building material, firewood and charcoal production. These are located near the highly populated places and near the ports from where the mangrove forest products are transported to be sold at the remote places. In these places the deforestation rate is about 36% on average.

The local communities are selective on cutting mangroves. They select large trees or cut the branches they need. Further, they cut the trees at the height 0.5-1 m above the ground, allowing for easy regeneration. However, they clear all the big trees as they go along, probably due to difficulties they have in getting through the dense mangrove forest, and also they need to be close to dry land to be able to prepare the charcoal stoves. Figure 3.8 shows a mangrove forest being exploited for poles, firewood and charcoal production. It can be seen that they cut mangrove at about 40 cm to 100 cm height from the ground, allowing for regeneration.

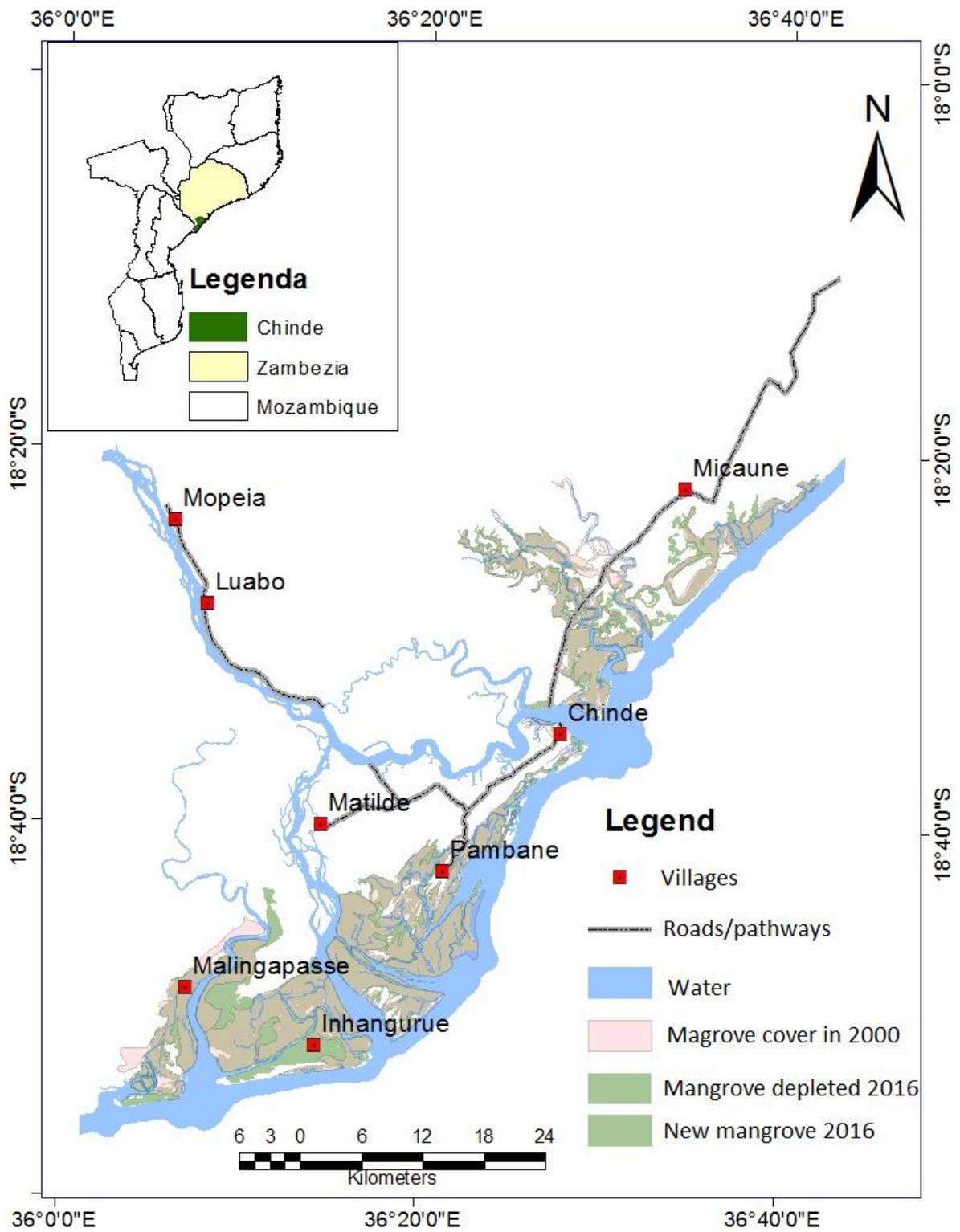


Figure 3.7. Mangrove cover in the Zambezi delta as estimate based in satellite imageries of 2016. From present study.



Figure 3.8. A mangrove tree being cut for charcoal production. Bairro Aeroporto, Chinde, October 2016. From present study.

Exploitation of the resources provided by mangrove ecosystem services

The major resources are fishery products inside the mangrove creeks and estuaries and in the adjacent coastal waters. The fisheries products include shrimps and crabs. Other ecosystem mangrove values include the protection of the coast against erosion, carbon sequestration, etc. Further, the mangrove creeks and estuaries are used for maritime transport and in addition mangrove swamps are used by local communities for traditional rituals.

3.11. Livelihood activities in the Delta

The major livelihood activities in the Delta are as follows:

- Agriculture
- Fishing
- Mangrove forest products harvesting

Agriculture is mainly practiced for subsistence while fisheries and mangrove forest product harvesting are used for generating income.

During the survey it was noticed that direct mangrove harvesting is mainly practiced by women while men go fishing. The primary activity of women is agriculture, and so, mangrove harvesting is practiced to supplement the house income. Figure 3.9 shows a mangrove collector in a mangrove creek in the Chinde village, Bairro de Hospital. He was recorded in a video during the field visit in October 2016. In the interview he stated producing about 10-30 kg of crabs a day, and that was able to sustain his family out of mangrove production.



Figure 3.9. Mangrove crab collector in a mangrove creek in Chinde, Bairro de Hospital, Chinde, Zambezi Delta, October 2016 (present study).

4. Methodology

The aim of this study is to estimate the economic value associated with mangroves and the economic benefits that can be harnessed in the future by sustainably managing them wisely. For this purpose, a rapid ecological-economic-livelihood assessment methodology as applied by IUCN in Laemson National Park, Ban Bang Man and Ban Naca villages, Ranong Province, Thailand; a survey based evaluation method, focusing on resources of value to livelihoods, assessing non-market as well as market values, and involving communities. The detailed economic valuation techniques used are as follows:

- Replacement costs, the cost of replanting mangrove;
- Effects on production, mainly related to direct mangrove harvesting products such as timber, firewood and charcoal and those derived from mangroves such as fisheries, all of them with a market value;
- Damage costs avoided, mainly referring to protective value of mangrove against erosion, estimated mainly based on the value of the infrastructures to be destroyed.

4.1. Total economic benefit of ecosystems

The economic benefit of ecosystems was evaluated using market price from the primary producers. The study focused in the following **direct benefits** of mangrove ecosystems, which are the most used in the area:

- **Timber**, the amount and price of timber for building both in the producers and in the consumers.
- **Fuelwood** (charcoal and firewood), the amount and price of charcoal and of firewood both in the producers and in consumers.
- **Fisheries production**, the amount and price of fish, crustaceans and molluscs both in the producers and in the consumers.

And in the following **indirect benefits** of mangroves ecosystems:

- **Damage avoided**, estimated based in the cost of infrastructures threatened to be destroyed by erosion where mangrove has been removed.

The surveys in the field aimed at collecting data that would enable to:

- estimate the production of timber, firewood, charcoal and fish products;
- market prices;
- estimate the infrastructure likely to be affected by erosion and estimate their cost.

The data were obtained in the Chinde district and surroundings, Malingapasse in Marromeu, Luabo and Micaune. The household survey was conducted to estimate the contribution of mangrove products and those derived from mangrove ecosystem services in the household income. The result was given in *Income per House Hold per year (HH/Year) units*, considering the total mangrove area, as estimated in 2014. The benefits from the mangrove products and those derived from mangrove

ecosystem services were compared as to demonstrate the sustainable benefit of conservation of mangrove.

In addition, the following information was collected:

- Maritime transports, major routes, goods transported and value;
- Carbon sequestration and trading.

4.2. Surveyed locations and the size of survey sample

The surveys were conducted in the suburbs, villages, markets and artisanal fisheries centers through semi-structured questionnaire surveys, which were filled by interviews to individuals houses holds and to targeted groups, namely artisanal fisherman, fish traders, charcoal traders and mangrove pole and firewood producers and traders. The questionnaires are presented in annex II. In addition, meetings were held with stakeholders at provincial, district and community levels. About 3 meetings were held and the list of participants are presented in Annex III. Table 4.1. present the main stakeholders.

The sites surveyed are presented in Figure 4.1., and were as follow: Chinde – Aeroporto, Chinde – Hospital, Chinde – Amarelo, Chinde – Arrozal, Chinde – Inhalume, Chinde – Fina, Matilde, Pambane, Inhagurie, Luabo, Malingapasse, and Micaune – Tivarone. Table 4.2 presents the coordinates of each site. The sampling unit was households within the Zambezi Delta, and the sampling size was estimated according to the following formula:

$$n \geq \frac{N}{1 + Ne^2} \quad [1]$$

Where n = sample size, N= total number of households in the area (37,640), and $e = 0.05$ design margin of error (5 percent error assigned). Hence, the minimum sample size is 400 households, or the sampling size should be $n \geq 400$.

Data and information processing

The data and information was recorded and processed in Excel. GIS was applied to map the surveyed locations.

Table 4.1. Main stakeholders for the Zambezi Delta mangrove conservation and sustainable use.

Name	Organization/Position
Diogo Borges Davide	Provincial Director of land, environment and rural development
Fialho Nehama	UEM-ESCMC
Pedro Armando A. Vírgula	Administrator, Chinde District
Eugénio Mussa Gocinho	Permanent Secretary, District of Chinde
Vale Osório Limane	Head of the District Posto, Chinde
Raquel Suméloi	Régulo – Rainha, Chinde
Jaime Gomes Amade	Régulo, Chinde
Daniel Maula	RADESA
Tomas Victorino Amissande	ANAM

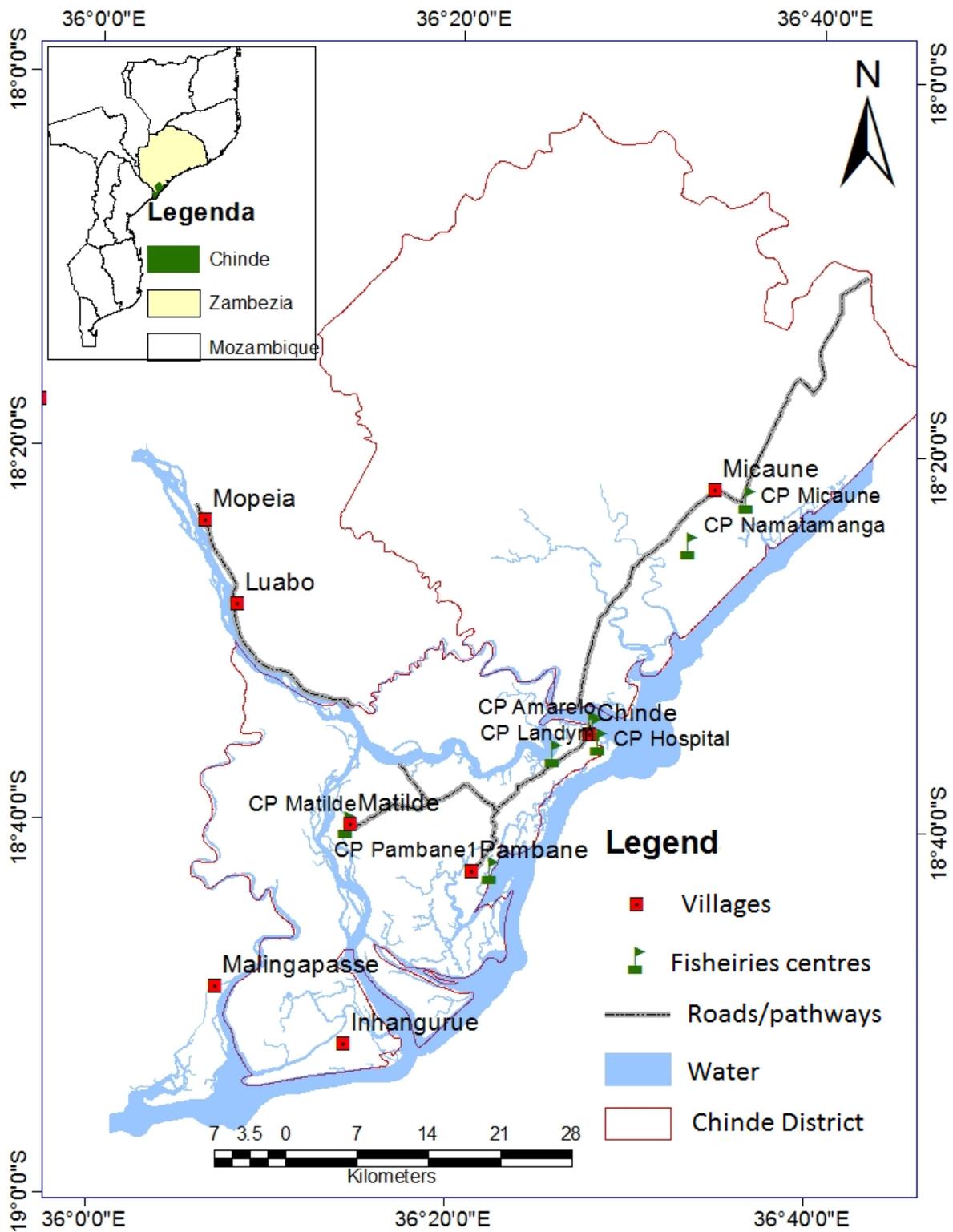


Figure 4.1. Map showing the locations that were surveyed, in Zambezi Delta.

Table 4.2. The coordinates of the villages surveyed.

Village	Position	
	Latitude S	Longitude E
Chinde - Aeroporto	18° 34' 46.56''	36° 27' 15.88''
Chinde - Hospital	18° 35' 06.44''	36° 27' 58.72''
Chinde - Amarelo	18° 34' 52.56''	36° 27' 57.84''
Chinde - Arrozal	18° 35' 18.48''	36° 27' 25.92''
Chinde - Inhalume	18° 35' 18.32''	36° 27' 45.42''
Chinde - Fina	18° 35' 12.48''	36° 28' 04.01''
Matilde	18° 40' 49.44''	36° 22' 27.84''
Pambane	18° 40' 30.00''	36° 22' 30.00''
Inhagurue	18° 52' 12.00''	36° 13' 48.00''
Luabo	18° 24' 18.00''	36° 06' 36.00''
Malingapanse	18° 40' 23.52''	36° 06' 36.00''
Micaune - Tavarone	18° 15' 20.16''	35° 39' 05.76''

5. Results - Economic ecological value of mangroves in the Zambezi Delta

The present Chapter reports the result of the estimated value of the ecosystem services provided by mangroves in the Zambezi Delta. Monetary values were assigned to each of the mangrove services attributes. The values were obtained through structured interviews and through direct findings in the field. This estimate represents the benefits that could be lost if mangrove are not maintained or the equivalently cost of policy inaction towards conservation of mangroves. Further, the values presented in this report reflect those that are available in the Delta and so our valuation results represent only a partial set of ecosystem services.

In order to allow direct comparison of the results of the preset study with others elsewhere, all value estimates are standardized to US\$ per hectare per year at 2013-2014 price levels. The values that are reported in local currency are converted to US dollars using purchasing exchange rate of 1 US\$ to 30 MZN. It should be noted that it was not possible to assign the value of cultural services neither of storm buffering provided by mangroves.

The annual values are estimated considering the time horizon of the services. Total values or values estimated for a specified ecosystem service attribute are divided by the corresponding area in hectares to obtain a value per hectare. Values reported per person or per household terms are converted to per hectare basis by computing the implied total value, e.g. multiplying the per person value by the relevant population of ecosystem service beneficiaries identified in the study, and dividing by the area of the mangrove study site. The ecosystem services identified, through interviews and government reports, in Zambezi Delta are as follows:

- Provisioning of goods - timber, fuelwood, and charcoal;
- Habitat and nursery - breeding, spawning and nursery habitat for commercial fish species;
- Regulating - erosion control and storm buffering;
- Carbon sequestration;
- Cultural service;
- Maritime transport.

5.1. Provision of goods

Mangroves in the Delta provide timber, poles and firewood. Timber and poles are used for building houses, boats and furniture, and part of the firewood is sold directly to the customers and part is used to make charcoal, which is then sold. Different mangrove species offer wood products for specific use. Table 5.1 present the species of mangrove and the utility of each wood product.

Table 5.1. Mangrove species and the use of their wood products in the Zambezi Delta.

Mangrove species (Scientific name)	Mangrove species (Local name)	Utility
<i>Xilocarpus granatum</i>	Murrubo	Charcoal, Furniture
<i>Ceriops tagal</i>	Mucandara	House building
<i>Sonneratia alba</i>		House building, charcoal, furniture
<i>Avicennia marina</i>	N'vethe	House building, Charcoal
<i>Heritiera litorales</i>	Ncolongo	Furniture
<i>Bruguiera gymnorrhiza</i>	Pau-ferro	House building
<i>Rhizophora mucronata</i>	Nanthazira	House building

Figure 5.1. shows furniture built with mangrove wood (*Xilocarpus granatum*) and a typical house frame built with *Ceriops tagal* poles, Figure 5.2. shows the process of charcoal production from *Xilocarpus granatum* mangrove wood in a suburb of Chinde, Zambezi Delta and Figure 5.3. shows firewood from Micaune, landing in Chinde to be sold. Mangrove harvesting for timber, firewood and charcoal production is undertaken for income generation. This activity involves women (Figure 5.4).



Figure 5.1. Mangrove wood usage: (a) a chair built with *Xilocarpus granatum* mangrove wood (Pambane, Chinde, October, 2016) and (b) a house frame built with *Ceriops tagal* poles. (Bairro Farol, Chinde, Zambezi delta, October 2016).

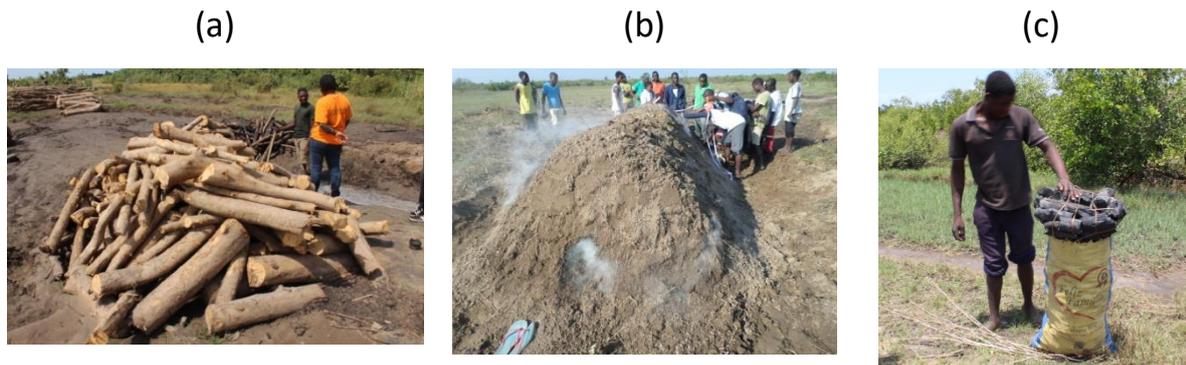


Figure 5.2. Mangrove wood usage for charcoal production: (a) wood of *Xilocarpus granatum* piled up for charcoal stove (Bairro Hospital, Eastern Chinde, Zambezi Delta, October 2016), (b) a charcoal stove burning (Bairro Aeroporto, Chinde, Zambezi Delta, October 2016) and (c) a bag of charcoal produced (Bairro Arrozal, Chinde, Zambezi Delta, October 2016).



Figure 5.3. Firewood obtained in Micacune, landing in Chinde to be sold in the village. (Chinde Beach, Zambezi Delta, October 2016).



Figure 5.4. Women involved in mangrove pole harvesting for house building. (Inhangume Village, Chinde, Zambezi Delta, October 2016).

5.2. Economic value of the mangrove direct products

The estimate of the provision value of mangrove was estimated based on the state of mangrove stands, conservation status and sustainable harvesting levels and considering the use for charcoal production and prices of 2014. It was not possible to assign values for furniture as the market for these products seemed to be limited in Chinde. Charcoal production was chosen because it is the primary choice for income generating from mangrove wood products and so, the main cause of mangrove depletion in the Delta.

Considering the allowed commercial size of a mangrove tree of 7.5m height, 2.5m perimeter, in an ideal forest density of 1800 per hectare, a charcoal efficiency of 20 bags using 13 trees, and considering further, that a tree would attain the commercial size in about 10 years, then, the sustainable harvesting would be 13 trees, corresponding to 20 bags of charcoal per hectare per month. For the price of 150MZN per bag of charcoal it gives a total of 3,000MZN, equivalent to US\$100 per hectare of mangrove per month or US\$1,200 per hectare of mangrove per year.

If considering that the Delta has 37,034 ha of mangroves area, the charcoal production would render US\$44,440,800 per year. And considering the 188,206 population of the Delta, the charcoal from mangrove would render nearly US\$236 per capita per year, equivalent to the average GDP per capita in Mozambique.

If mangrove wood product is used as poles for building, a tree can be harvested in 5 years, at the rate of 26 trees per hectare per month. Each pole can be sold at 100MZN, hence, earning 2,600 MZN, equivalent to US\$86 per hectare of mangrove per month, equivalent to US\$1,040 per hectare per year. Considering the total area of mangrove in the delta, mangroves would render US\$38,515,360, and considering the total number of population in the delta, the mangrove exploited as poles would render US\$204.64 per capita per year, slightly less than that of charcoal. The value suggested in the present study falls well below the estimate in other places of the world, for precautionary reasons, but also due to the differences in market demand. Cabrera *et al* (1998) estimated the total and net revenue associated to mangrove exploitation for charcoal, in Terminos Lagoon, Campeche, Mexico, at US\$318,816 ha⁻¹ yr⁻¹ and US\$234,641 ha⁻¹ yr⁻¹ respectively, and the total and net revenue for building material estimated at US\$73,095 ha⁻¹ yr⁻¹ and US\$50,533 ha⁻¹ yr⁻¹.

It is believed that furniture production would render more, though it would require up to 20 years for a tree to grow to the commercial size to be harvested for timber for furniture. However, we were not able to obtain the prices for furniture as the furniture trade is not developed in Chinde. According to Gan (1995), roughly 1,050 ha of forests are cleared annually over a 30 year rotation cycle, with an average yield of 17.4 tons ha⁻¹ yr⁻¹.

5.3. Protective function

The village of Chinde is eroding at the rate of 30m per year (Hoguane and Tauacale work, unpublished data) in a section of about 1,500km along the beach (Figure 5.5). Based in local testimonies the erosion may have been initiated in the late 80's, when many people fled into Chinde Island seeking refuge from the civil war, thinking that Chinde, being an island, was safer. The immigrant people built their houses from mangrove poles extracted from the site that is now eroding. Clearly, the cause of the current erosion is the mangrove deforestation that occurred in the late 80's.

On the southern part, though, there is accretion. Storms built a sand barrier along the beach, which creates a protection and enables a suitable environment for settlement of mangrove seeds. Subsequently, there are strips of flourishing mangrove forests parallel to the coast.

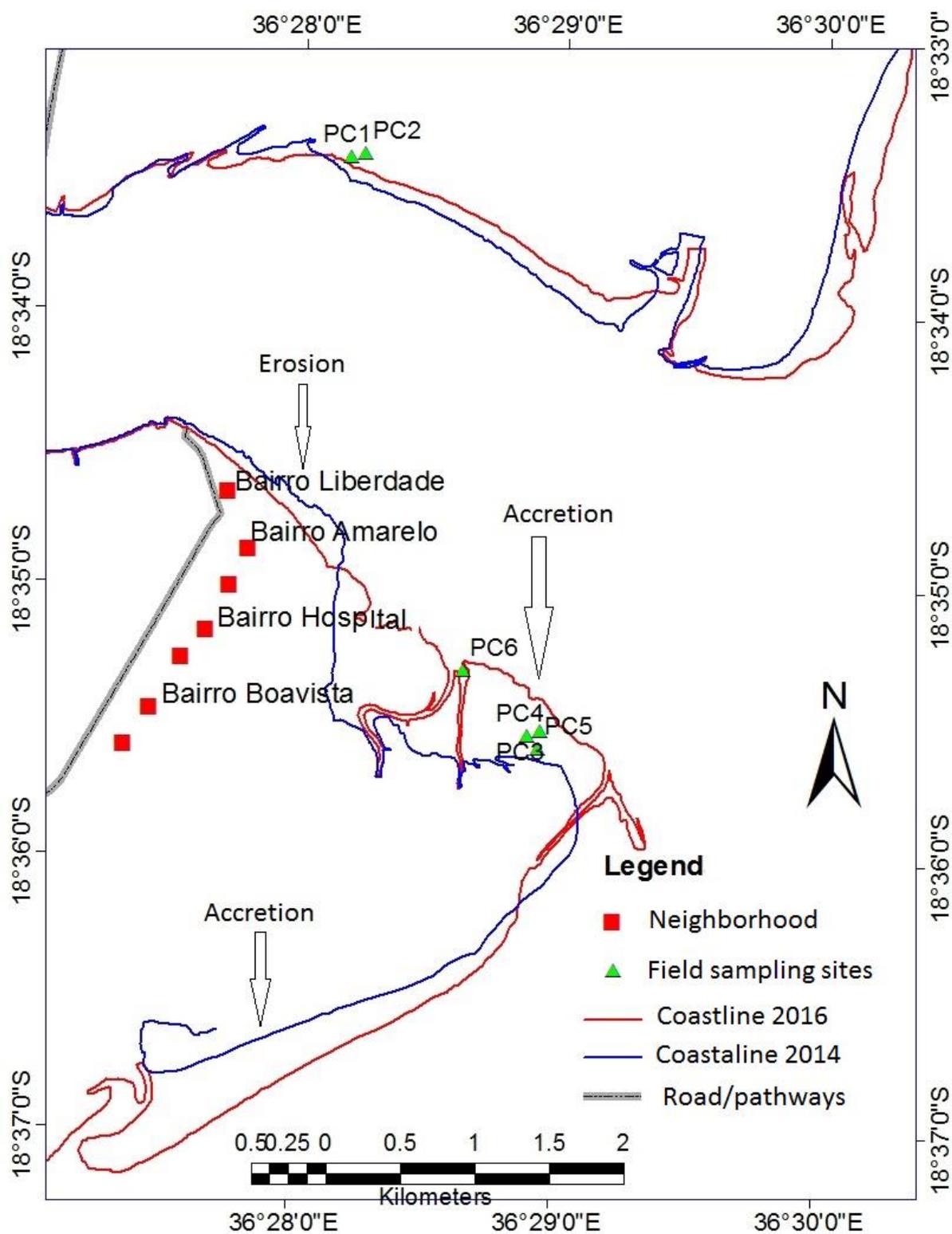


Figure 5.5. Erosion and accretion in the Chinde Beach, Chinde Village, October 2016.

The testimonies indicated further, that the initial Chinde Village, called Chinde 1, was completely eroded, forcing the village to move and settle further inland, and termed Chinde 2. This was also

swept away by erosion, forcing the village to move further to the actual position and now termed Chinde 3, which is also threatened by erosion. Figure 5.6 illustrates the extent of erosion in the Chinde Beach.



Figure 5.6. View of the extent of erosion in Chinde beach, Chinde Village, October 2016.

Various attempts to prevent erosion were tried with no success. The Government with the support of NGO's organized the communities to set a protective wall with sacs, sand and poles along the beach, and in addition, traditional ceremonies and rituals were held, in order to stop erosion and create an environment enabling the mangrove seeds to settle and grow. All these attempts did not render the desired result and the erosion continued.

Currently an extension of 1,500 m along the beach with 300 m width is being threatened by erosion (Figure 5.7), putting in danger the following infrastructures: new infrastructure composed of a harbor (Figure 5.8) and a building for maritime administration (Figure 5.9), 3 warehouses, 8 conventional brick houses and about 380 combined timber and cement houses (Figure 5.10) threatened by erosion. Typical timber houses presented in Figure 5.10 (right) are estimated at US\$1,600.



Figure 5.7. Area adjacent to Chinde Beach threatened by erosion. The marked area show the infrastructures treated by erosion. Chinde Village, October 2016.



Figure 5.8. An harbor being built in Chinde, Chinde Village, October 2016.



Figure 5.9. The building for maritime administration in Chinde, Chinde Village, October 2016.



Figure 5.10. A brick house (left) and typical house (right) in Chinde, Chinde Village, October 2016.

5.4. Economic value of the protective function of mangroves

The estimate of the protective value of mangrove was made based on the “expected damages avoided by maintaining the ecosystems protective functions”, namely, the costs of replacing infrastructure threatened. Further, it was considered that a strip of mangrove of about 400-500m wide and 1,500m long would be sufficient to protect the village against erosion.

It should be noted, however, that this cost-based approach for valuing protective value of mangrove ecosystems tend to undervalue the protective function of mangroves because it does not take into account the tendency for people to be risk-averse, and to be willing to pay more to prevent risks, and it does not take into account for the value of avoided injuries and fatalities as suggested by Spaninks and van Beukering (1997).

The estimate value of the infrastructures threatened is as follows: the harbor and the maritime administration building are both estimated at 17,439,383.80MZN, which is equivalent to about US\$581,312.79; the warehouses are estimated at 2,000,000.00MZN, equivalent to US\$65,000.00 each; the brick houses are estimated at 800,000.00 MZN, equivalent to US\$25,000.00 each and combined timber and cement houses are estimated at 40,000.00MZN, equivalent to US\$1,300.00. Table 5.2 summarizes the total cost of the threatened infrastructures in local currency and in American Dollars.

Table 5.2. Estimate of the economic value of the protective function of Mangrove in the Zambezi Delta.

Type of infrastructure	Quantity	Amount		
		MZN	MZN	US\$
Harbor and Maritime Administration building	1	17,439,383.80	17,439,383.80	581,312.79
Warehouse	3	2,000,000.00	6,000,000.00	200,000.00
Brickhouse	8	800,000.00	6,400,000.00	210,333.33
Typical pole and cement house	380	40,000.00	15,200,000.00	506,666.67
Total			45,039,383.80	1,498,312.79

Note: Exchange rate was 30MZN to a dollar.

Considering that a strip of mangrove of 1,500m long and 500m wide, with an area of 750,000 m², would be sufficient to prevent erosion in Chinde, the value of mangrove protection would be about 60.00MZN per square meter, or about 600,500.00MZN per hectare of mangrove, equivalent to US\$2.00 per square meter, or about US\$ 20,000.00 per hectare of mangrove per year.

Although the value of mangrove protection would depend on a number of factors including the level of the economy of the country, the cost of services, the infrastructures at risk as well as the stand of mangroves, which includes the tree species, height and density and the extent of mangrove area, the estimate found in the present study falls within most findings in the world. Rao *et al* (2015) conducted a global study to estimate the ecosystem service value of specific coastal ecosystems, namely, coastal wetlands, mangroves and coral reef, with regard to coastal protection, and using meta-analytic regression method the values they obtained ranged from USD0.4 to US\$2,529.9 ha⁻¹ year⁻¹. Koch *et al* (2009) examined the variability observed in wave attenuation provided by marshes, mangroves, seagrasses, and coral reefs and therefore also in coastal protection, and concluded that ecosystem service of coastal protection is also non-linear and dynamic. For instance space or extent of mangrove, the specie, density and height of mangrove trees are the main determining variables. Shuto (1987) suggested that a 20m or 100m wide mangrove belt would be sufficient to protect against tsunami waves of 3m and 6m high, respectively. Mazda *et al.* (1997) estimated that mangrove forests as wide as 1000m would be sufficient to reduce wave energy by 90%, depending on tree density (Massel *et al.* 1999). In very dense mangrove forests, full attenuation of wind-induced waves may occur within 30m of the edge, while low-density mangroves would require much wider vegetation cover, to obtain the same result (Komiyama *et al.* 2008; Massel *et al.* 1999). Koch *et al.* (2009) assuming a mangrove extent along a 10km coastline and adjusting the width, estimated the value of storm protection per unit area of mangrove and obtained the following

result: for mangrove area up to 300 ha the protective value was US\$119,723.79 ha⁻¹ yr⁻¹ and US\$71,496.01 ha⁻¹ yr⁻¹ for *Sonneratia sp* and *K candel*, respectively. At the maximum mangrove area of 1000 ha, the storm protection value was estimated at US\$159,405.72 ha⁻¹ yr⁻¹ for *Sonneratia sp* and US\$143,179.97 ha⁻¹ yr⁻¹ for *K candel*. Badola *et al.* (2003) valued the storm protection function of mangroves in India by cyclone using damage avoided method. They assessed the damage to houses, livestock, fisheries, trees and other assets caused by cyclones and storms and their result ranged from US\$1,454.13 to US\$6,918.62.

Storm buffering function of mangroves

The mangroves play an important role of buffering the storms in the Zambezi Delta, fact that is proven by the bend, leaning towards the land, of the mangrove trees fringing the ocean (Figure 5.11.). However, it was not possible to assign economic value because there were no houses nearby the places where bent mangroves were spotted.



Figure 5.11. Leaned mangrove proving the buffering effect against the storms along the beach in Chinde, Bairro Amarelo, Chinde village, October 2016.

5.5. Habitat and nursery

Mangroves provide breeding, spawning and nursery habitat for many commercial fish species. Some species are endemic in mangrove creeks and estuaries, others are either typical of freshwater or typical marine species that live temporarily in the mangrove creeks and estuaries for spawning, breeding, nursery or feeding.

Given the fact that for species caught in coastal waters either by artisanal, semi-industrial or industrial fleets it is difficult to trace which are related to mangroves, for the economic assessment of the ecological value it was considered the entire Sofala Bank. According to Simard *et al.* (2008) the mangrove area in Sofala Bank is estimated at 281,074 ha, also see Barbosa (2001).

Table 5.3 presents the catch and catch species composition of the artisanal, semi-industrial and industrial fisheries in Sofala Bank.

The species captured which are related to mangroves as described in FishBase by Rainer, Daniel Pauly (2014) and in the *Encyclopedia of Fishes* by Gareth (1998), are included in Appendix I.

5.6. Economic value of the habitat nursery services of mangrove

Table 5.3 presents the catch of mangrove related fish species (those that breed, live or feed in mangrove related ecosystems) of the whole Sofala Bank during the year 2014. The catches were 29,370 tons, 4,454 tons and 25,105 tons for artisanal, semi-industrial and industrial fisheries respectively, totalling 58,468 tons of fish per year. The Penaeidae shrimp dominated the crustacean catch, with about 6,398 tons, representing 10.9% of the total fish catch, from which 1,192 tons are from artisanal fisheries. Crabs made up to 1,155 tons, representing 2% of the total fish catch; fish made up to 50,201 tons, representing 85.9% of the total fish catch, dominated by Engraulidae fish species, followed by Clupeidae, Sciaenidae and Ariidae. The remaining are fish species less representative ($\approx 1,2\%$).

Table 5.3. Fishing Catch in Sofala Bank in 2014.

Commercial category	Species family name	Artisanal		Semi-industrial		Industrial	
		Catch (Tons)	%	Catch (Tons)	%	Catch (Tons)	%
Shrimp	Penaeidae	1,197	4	170	4	5,031	20
	Sergestidae	299	1				
	Portunidae	23	0	126	3	1,006	4
Crab	Others					201	1
	Engraulidae	3,949	13	744	17	4,427	18
Fish	Clupeidae	6,343	22	394	9	201	1
	Sciaenidae	6,882	23	1,269	28	428	2
	Trichiuridae	1,436	5	263	6	402	2
	Carangidae	359	1				
	Ariidae	2,932	10	350	8	1,006	4
	Haemulidae	1,137	4	131	3	805	3
	Scombridae	1,616	6	263	6	604	2
	Mungilidae	598	2				
	Sphyraenidae	60	0	88	2	1,610	6
	Leiognathidae					805	3
	Polynemidae					604	2
	Psetodidae					579	2
	Muraenidae					402	2
	Platycephalidae					226	1
	Therapon					277	1
	Drepanidae					0	0

	Cynoglossidae		131	3	0	
Cephalopoda	Sepiidae				528	2
	Loliginidae				201	1
Rays					327	1
Sharks		145	0			
Other fish		2,394	8	525	12	5,433
Total		29,370	100	4,454	100	25,105

Source: Catch statistics, Fisheries Research Institute and Small Scale Fisheries Development, Mozambique.

Table 5.4 gives the average price of fish, from the fishermen. The total gross income from fisheries, artisanal, semi-industrial and industrial was 5,072 Million Meticals, equivalent to 169 Million American Dollars from fisheries per year. The Penaidae shrimp contributed with US\$42,6 million, representing about 25% of the total income; the small pelagic and demersal fish species contributed with US\$8.9 million, representing about 48% of the total fish income.

Table 5.5 gives the catch and the gross income per unit of mangrove area and per year, of the fisheries in Sofala Bank, for the year 2014, considering a total mangrove area of 281,074 ha for the entire Sofala Bank. The average fish production yield was 209 kg ha⁻¹ yr⁻¹; where the highest production yield was from fish, with 178.6 kg ha⁻¹ yr⁻¹, followed by shrimp with 23.8 kg ha⁻¹ yr⁻¹. The overall gross income from fish products in Sofala Bank was US\$600 ha⁻¹ yr⁻¹, with the highest contribution from fish (US\$419.07 ha⁻¹ yr⁻¹), followed by shrimp (US\$152.11 ha⁻¹ yr⁻¹).

Table 5.4. Estimated gross income from fisheries in Sofala Bank for the year 2014.

Fish product	Quantity (Tons)	Unit Price (MZN/Ton)	Total Price	
			(MZN)	US\$
Penaide Shrimp	6,398	200,000	1,279,658,000	42,655,267
Small krill-like prawns	299	10,000	2,992,000	99,733
Crab	1,356	100,000	135,644,000	4,521,467
Small pelagic fish	41,434	26,000	1,077,283,000	35,909,436
Demersal	9,203	150,000	1,380,422,000	46,014,050
Big pelagic fish	5,380	200,000	1,075,967,000	35,865,567
Squids	729	100,000	72,950,000	2,431,650
Sharks and rays	472	100,000	47,202,000	1,573,383
Total	65,272		5,072,117,000	169,070,553

Table 5.5. Estimated catch and gross income per hectare and per year from fisheries in Sofala Bank for the year 2014.

Commercial category	Catch (kg ha⁻¹ yr⁻¹)	Gross income (US\$ ha⁻¹ yr⁻¹)
Shrimp	23.8	152.11
Crab	4.8	16.09
Fish	178.6	419.07
Cephalopoda	0.7	8.65
Sharks and Rays	1.7	5.60

The average fish production yield and the gross income per unit area of mangrove, of 209 kg ha⁻¹ yr⁻¹ and US\$600 ha⁻¹ yr⁻¹, respectively, obtained in the present study, fits within the findings from other studies. Cabrera *et al* (1998) estimated the catch and total revenue associated to mangrove dependent fish species, in Terminos Lagoon, Campeche, Mexico, at 323 kg ha⁻¹ yr⁻¹ and US\$1,529 ha⁻¹ yr⁻¹ for shrimp, respectively. Christensen (1982) estimated the commercial harvest by small, medium and large scale fishermen of fish, trash fish, prawns and shrimp, based on a weighted market price of in Asia and obtained that the catch of mangrove related shrimp were 80kg ha⁻¹ yr⁻¹ accounting for US\$30 ha⁻¹ yr⁻¹, and US\$100 ha⁻¹ yr⁻¹ for fish species such as mullet, snapper, whiting. Ruitenbeek (1992) estimated the revenue of sustainable shrimp harvesting in Bintuni Bay, Irian Jaya, and his result US\$94 ha⁻¹ yr⁻¹ and for bycatch of shrimp fisheries was estimated at US\$23 ha⁻¹ yr⁻¹. Lal (1990) Fiji estimated the total production of commercial (147 kg) and subsistence fisheries (184 kg) harvest in mangrove-ecosystem at 331 kg ha⁻¹ yr⁻¹ based on a weighted average market price at US\$60-US\$240 ha⁻¹ yr⁻¹ with average of US\$100 ha⁻¹ yr⁻¹. Gammage (1994) estimated the annual sustainable shrimp harvest based on local market prices in El Salvador and obtained 5.5 kg ha⁻¹ yr⁻¹ corresponding to US\$77 ha⁻¹ yr⁻¹. According to Hatcher *et al.* (1989) the fish gross income from fish production related to mangrove ecosystem ranged from US\$21 ha⁻¹ yr⁻¹, from Bangladesh to US\$ 2,773 ha⁻¹ yr⁻¹, in Malaysia, Philippines registered US\$561 ha⁻¹ yr⁻¹ and Brazil US\$769 ha⁻¹ yr⁻¹. Hutchison *et al.* (2015) conducting a literature search on papers published on mangrove fishery values found that the inshore mixed species production, attributed to mangroves, varied from 20.9 to 1,195 kg ha⁻¹ yr⁻¹, averaging to 120.1 kg ha⁻¹ yr⁻¹, and the income varied from 0.2 to 2,164.1 US\$ ha⁻¹ yr⁻¹, averaging to 106.1 US\$ ha⁻¹ yr⁻¹; the inshore crab production varied from 4.1 to 232.8 kg ha⁻¹ yr⁻¹, averaging to 45. kg ha⁻¹ yr⁻¹, with average income of 423.4 US\$ ha⁻¹ yr⁻¹; the offshore prawns production varied from 9.3 to 180.1 kg ha⁻¹ yr⁻¹, with average of 122.3 kg ha⁻¹ yr⁻¹, and the income range of 24.3–1,394 US\$ ha⁻¹ yr⁻¹. However, it should be noted that the catch and the income depends on a number of factors including the fishing facilities and effort, market demand cycle as well as the stand of mangrove ecosystem conservation.

5.7. Carbon Sequestration

Mangrove forests have the ability to sequester carbon from the atmosphere and store in soil and in dead roots (Alongi, 2014), contributing to reduce greenhouse gases in the atmosphere and mitigating the effect of global climate change. Hence, they are carbon sinks. Mangroves account for only approximately 1% (13.5 Gt year⁻¹) of carbon sequestration by the world's forests. According to

Stringer *et al.* (2014) the mangroves in the Zambezi Delta sequester about 463 Mg ha⁻¹ yr⁻¹. The figure falls within the findings in mangrove ecosystems in other parts of the world. According to McLeod (2011) the average world carbon burial rate for mangrove was estimated at 2.26 t C ha⁻¹ yr⁻¹; earlier estimate of the average standing stock of carbon stored in mangrove for the whole mangrove in Mozambique, by Fatoyinbo *et al* (2008), was 40.5 Mg C ha⁻¹ yr⁻¹.

The carbon sequestered by mangroves can be sold through a carbon credit trade mechanism. The concept was agreed in Kyoto Protocol of 1997, and consists of placing a monetary value on the cost of polluting the air. A credit is a measure representing one megatonne (a mass equal to 1,000 kilograms) of carbon dioxide. This is either saved from being emitted or removed from the Earth's atmosphere by, for instance, mangrove vegetation. The market price of carbon is on average US\$13 per tonne of CO₂, according to Carbon Planet, one of the leading carbon credit traders. Hence, the carbon sequestered by the mangroves in the Zambezi Delta is worth US\$6,000 per ha⁻¹ year⁻¹, and considering the total area of mangrove in the Delta the total income from carbon trade would be 223 Million American Dollars per year.

5.8. Cultural service

Cultural services are present in the Delta and consist mainly in rituals and ceremonies conducted by the traditional leaders and healers, and aiming at asking to the ancient's blessings for productive fisheries. However, it was not possible to assign any economic value to the cultural function of mangroves.

5.9. Maritime and inland water transport

Mangrove creeks and estuaries provide vein of communication which holds the maritime and inland waterway transports convenient and affordable. In addition, the maintenance of water veins of communication is cheaper compared to terrestrial transports where roads and bridges are to be built and maintained. The main maritime and inland waterways in the Zambezi Delta are presented in Figure 5.12. In the delta there are about 38 boats and canoes operating and licensed for passengers and goods transport. Figure 5.13 shows a boat used to transport passengers and goods in the delta. Table 5.6 presents the average number of passengers and the volume of goods transported per year in the Delta. Through the Delta, the average amount of passengers transported per year is about 200,000 and nearly 300 tons of goods, rendering a gross income of about 19 million meticaís equivalent to US\$64,000 per year on the transport of passengers and about 6 million meticaís, equivalent to US\$200,000 per year on the transport of goods.

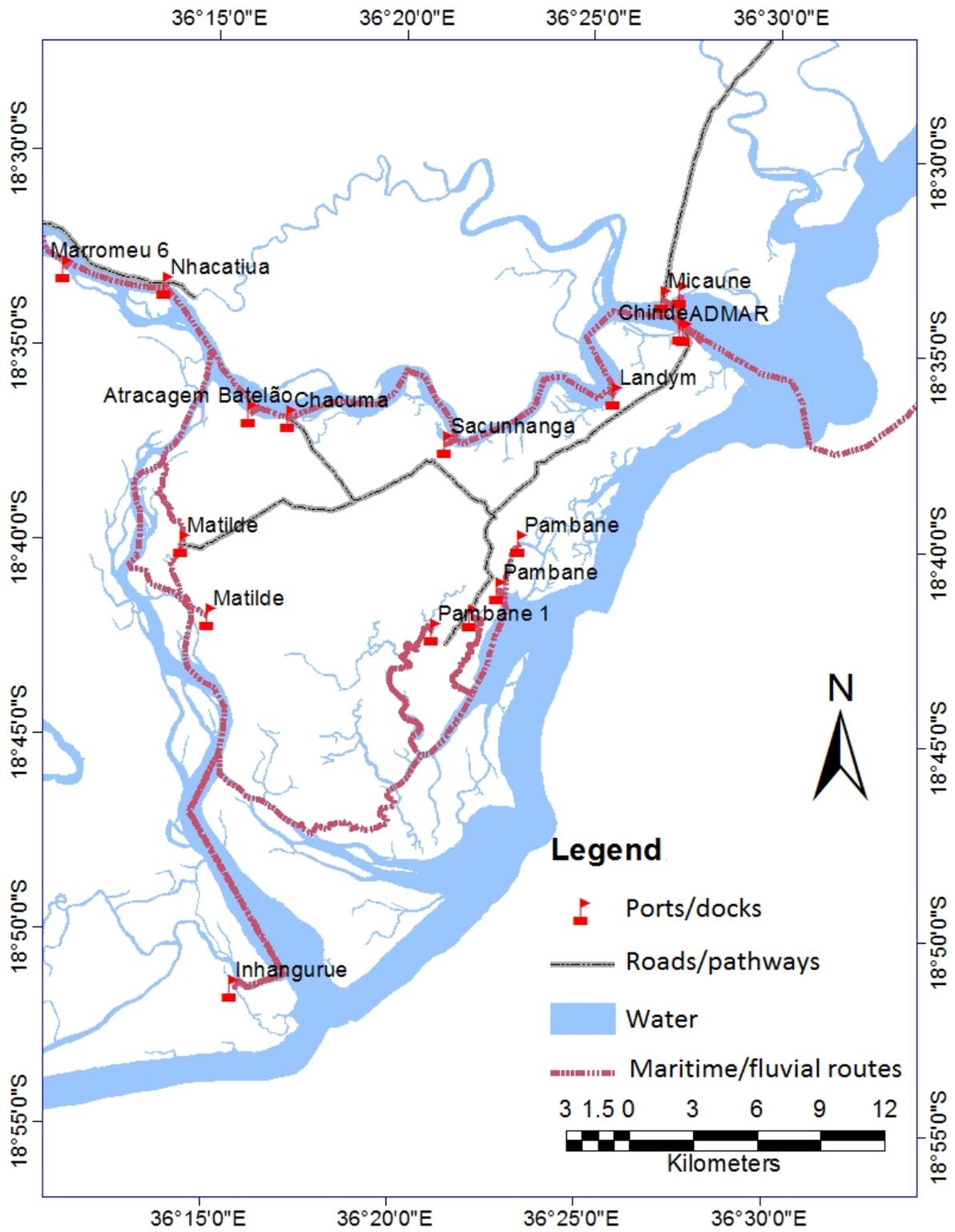


Figure 5.12. Major maritime and inland waterway routes in the Zambezi Delta, October 2016.



Figure 5.13. A boat used for transport of passengers and goods in the delta, Nhacatiua, October 2016.

Table 5.6. The major maritime and inland waterway and average number of passengers transported per year.

Maritime and inland water routes	Passengers		Total income	
	Unit price (MZN)	Number	(MZN)	(US\$)
Chinde - Maromeu	200	43,200	8,640,000	288,000
Chinde - Luabo	150	50,400	7,560,000	252,000
Chinde - Inhacatiua	50	28,800	1,440,000	48,000
Chinde - Micaune	40	21,600	864,000	28,800
Chinde - Rio Maria	20	18,000	360,000	12,000
Chinde Sede - Mucandaia (Bairro Centro) Sede	10	20,700	207,000	6,900
Total		182,700	19,071,000	63,5700

6. Results - Households survey on the value of mangroves

Approximately 573 households (Table 6.1.), of which about 22% were women, distributed in 12 villages (Figure 4.1 and Table 4.2) were interviewed. The entire Zambezi Delta region has an estimated number of 37,640 households, according to population census of 2011. Hence, the sampled population represented about 1.5% of the total population of the Delta, which complies with the sampling size criteria stated by the Equation [1].

6.1. Occupational profile

The primary activities identified were those related to mangrove harvesting for timber, firewood and charcoal production; fisheries and agriculture and the combination of two or three of primary activities and others. The category of others include activities such as trade, arts and crafts and small proportion of civil servants. The agriculture is mostly practiced for subsistence and the mangrove harvesting and fisheries are mainly carried out for income generation. During the interviews it became clear that agriculture is practiced in the majority of households, and often not reported, perhaps because since it is not considered as an income generating activity, it is overlooked in the household income. Figure 6.1(a) presents the livelihood activities per village surveyed. The most practiced activities are fishing and agriculture and the combination of mangrove harvesting and either agriculture or fishing. Relatively high proportion of mangrove harvesting for timber and firewood and fisheries was recorded in the villages located near the mangrove and the ocean, such as Chinde Village (Amarelo, Fina, Arrozal), Matilde, Inhangurue, Pambane, where the main livelihood activities are fisheries and mangrove harvesting. In the villages located far away from the mangrove and the ocean, such as Luabo and Malingapasse the main activity is agriculture. Higher proportion of other activities were recorded near the highly densely inhabited villages such as Chinde Village (Amarelo, Fina, Arrozal) and in Luabo. Overall the most practiced activities in the delta are fisheries, agriculture, charcoal production and others, which include trade and arts and crafts (Figure 6.1(b)).

Table 6.1. Villages surveyed and number of households interviewed.

Village	No of households interviewed
Chinde - Aeroporto	26
Chinde - Hospital	56
Chinde - Amarelo	43
Chinde - Arrozal	67
Chinde - Inhalume	53
Chinde - Fina	26
Matilde	54
Pambane	128
Inhagurue	37
Luabo	28

Malingapasse	23
Micaune - Tavarone	32
Total	573

6.2. Age distribution per livelihood activity

Table 6.2. presents the age distribution by livelihood activity. The charcoal and timber production are mostly carried out by younger people, mostly age from 18 to 25, extending up to age 45, because they require a lot of physical effort. Fisheries, agriculture and trade are activities practiced by people of all active age, from 18 up to age 60, however, the majority of fishermen and trade groups are in mid age, 26 to 40, and the majority in agriculture group is in advanced adult age 46 to 50. Thoughtfully, fisheries and trade require more physical effort compared with agriculture. Fisheries involve going at sea or estuary earlier in the morning and work all day and sometimes during the night, exposed to weather hostility. Trade mostly involves travelling, carrying goods and marketing, which requires some physical effort, further, young people can better succeed in marketing than elder people. In addition, agriculture is practiced for subsistence, meaning that even the elder people practice it for living and have no other choice.

Table 6.2. Age range distributed per livelihood activity developed in the Zambezi Delta.

Age range	Charcoal prod.	Timber prod	Fisheries	Agriculture	Trade
18-20	10	2	4	2	3
21-25	10		8	5	5
26-30	7	4	10	4	6
31-35	5	3	5	2	11
36-40	7	6	8	8	7
41-45	6	2	5	3	7
46-50			1	21	
51-55	3		2	4	3
56-60	2	4	9	5	7

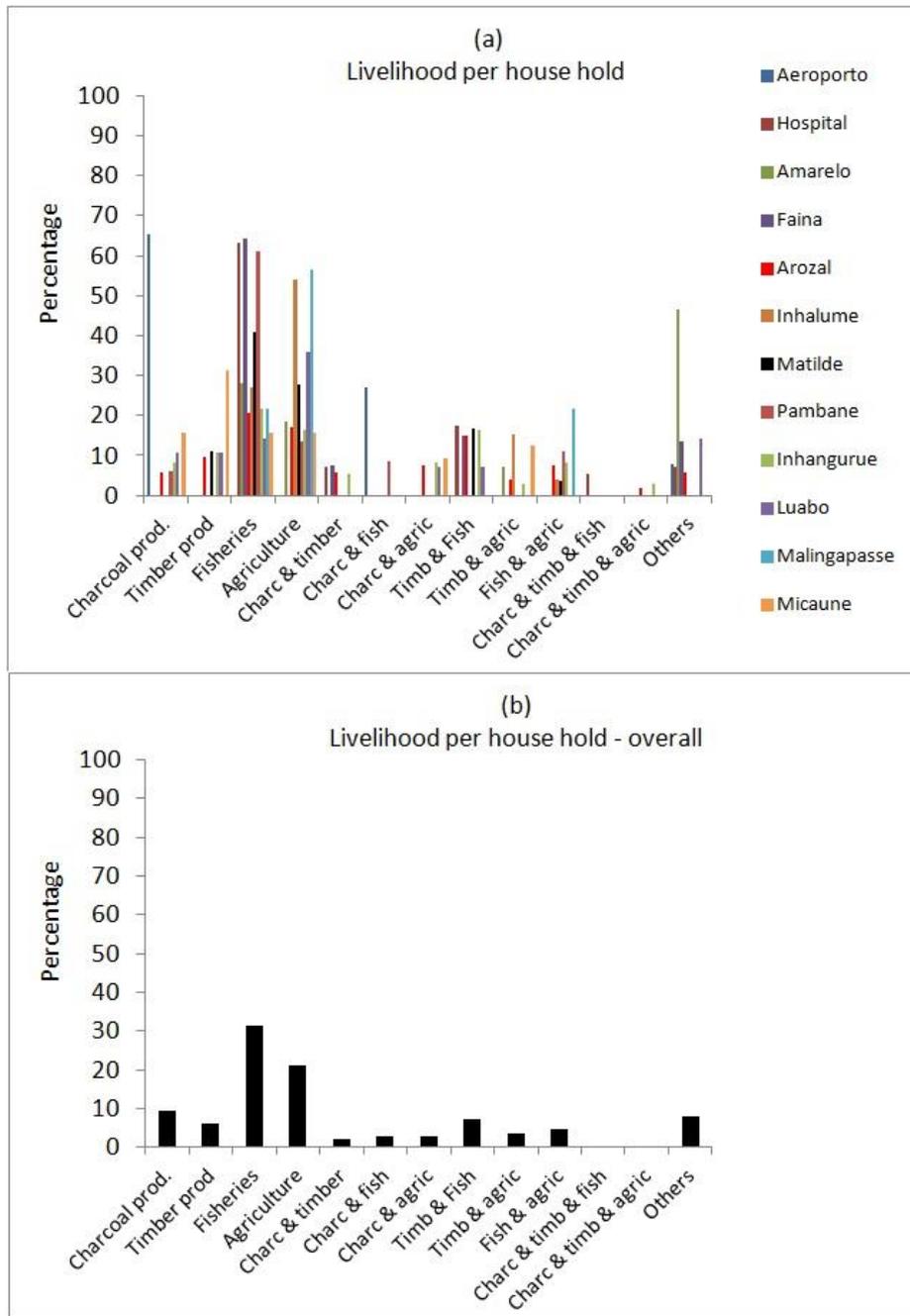


Figure 6.1. Occupational profile of the population in the Zambezi Delta.

6.3. Proportion of women in the livelihood activities

Figure 6.2 (a) presents the proportion of women in the different livelihood activities per surveyed village, as declared during the interviews. Most of women are involved in agriculture (30%) and combination of agriculture with either timber (8%) and charcoal (10%) production and fisheries (12%). Women are involved in trade, here classified as other activities. The fishery activities practiced mostly by women are mussel collection and operation of small fish trap in the estuary and mangrove creeks, capturing shrimp, fish and crabs. High proportion of women in charcoal production was recorded in Chinde-Aeroporto. Overall, women are involved in agriculture, charcoal production and a combination of mangrove harvesting and either agriculture or fisheries activities (Figure 6.2(b)).

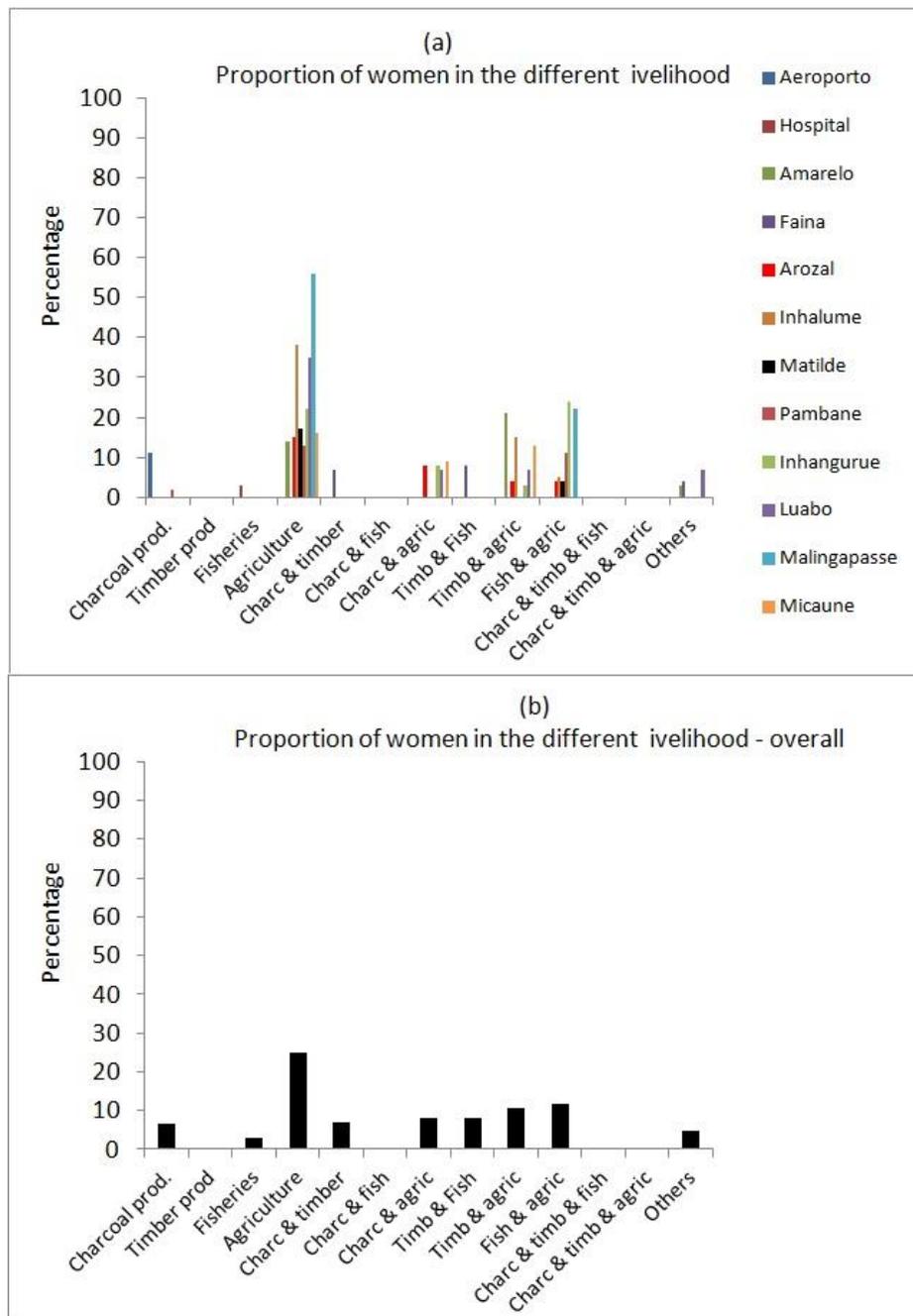


Figure 6.2. Proportion of women involved in each livelihood activities in the Zambezi Delta.

6.4. Alternative livelihood options to mangrove harvesting

The households were asked what they would prefer to do for living as an alternative to mangrove harvesting. The question was primarily addressed to those harvesting mangrove for timber, firewood and charcoal for a living but it was also addressed to those living off fishing in the basis that fisheries are dependent on mangrove. Figure 6.3(a) presents the result of these interviews. Most of the interviewed said they would prefer to practice agriculture (45%), other fisheries (13%) and trade (15%); few said they would practice honey production (8%) and a significant proportion said to have no other alternative (10%). Most of the fishermen chose agriculture as alternative and a significant proportion said to have no other alternative. Those harvesting mangroves for timber, firewood and charcoal production chose fisheries and agriculture as alternative livelihood activities. Beekeeping

for honey production was mostly chosen by people in Malingapasse, as honey production in terrestrial forest is already being practiced by the villagers. Surprisingly aquaculture was not a wide option, perhaps because it is an activity not well known in the region. Overall the most preferable alternative livelihood options are agriculture, fisheries, trade and beekeeping (Figure 7.3(b)).

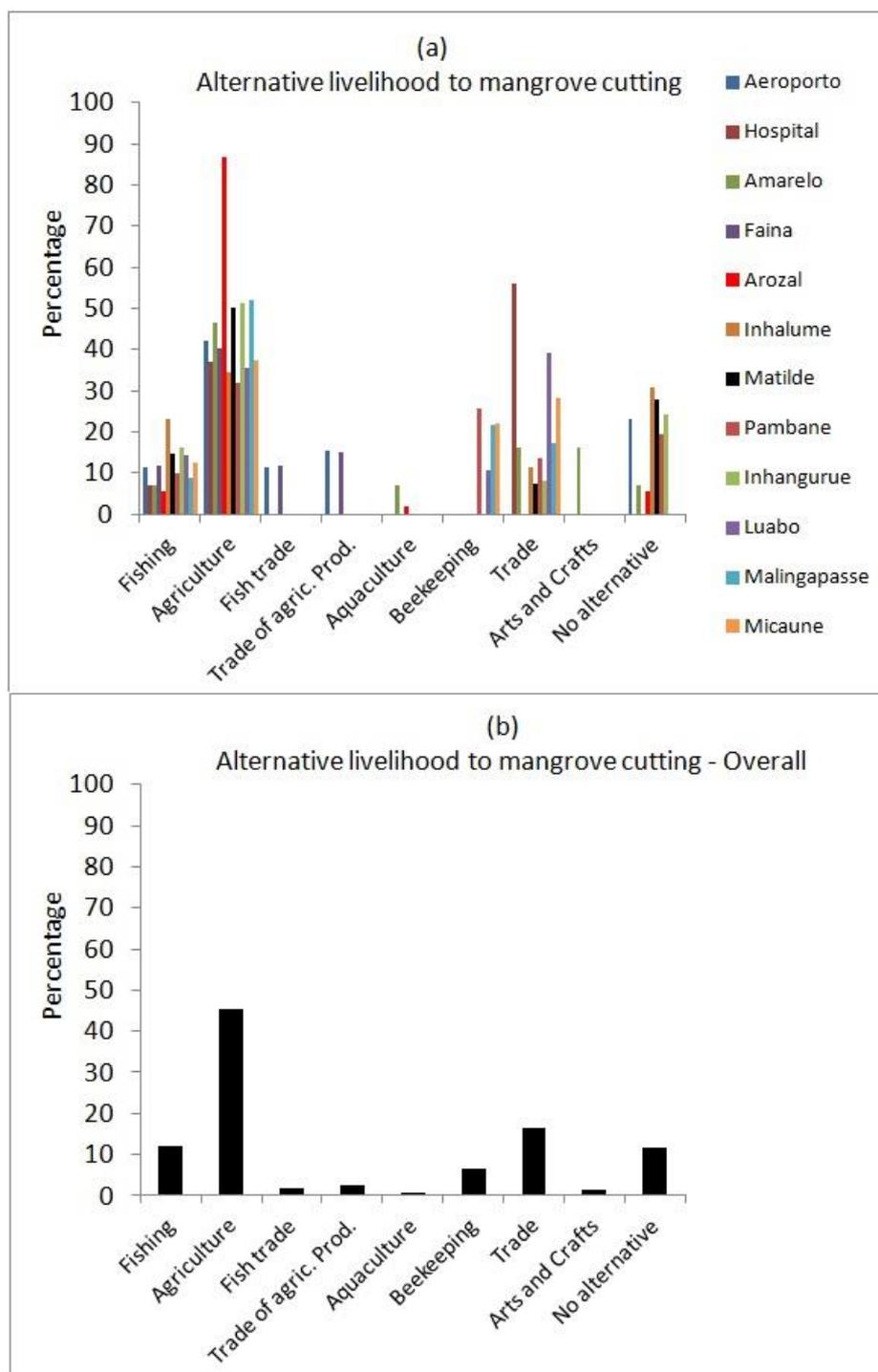


Figure 6.3. Household perception in relation to alternative livelihood activities in the Zambezi Delta.

6.5. Perception of the interviewed households on the value of mangroves

The households were asked different questions to assess their perception on the value of the mangrove. The questions addressed the following value of mangroves:

- Provisioning of goods - timber, fuelwood, and charcoal;
- Habitat and nursery - breeding, spawning and nursery habitat for commercial fish species;
- Regulating - erosion control and storm buffering;
- Cultural and ritual service;
- Medicine provider.

Further, it was asked whether they were willing to contribute, on a voluntary basis, to plant mangrove if there was a need. Questions related to assess the household perception on the role of mangroves in carbon sequestration and the role of mangrove creeks in facilitating maritime transports were not considered.

The question had two sections: one where the interviewed were to say whether they know if the mangrove can provide such services, and the other section where they were required to rank qualitatively the value of the service. In the question related with whether the mangrove provide such services they were required to state if the service is “present” or “absent” for the case when they knew that the mangrove provides the specified service or not, respectively. However, some of the interviewed understood that they were asked whether the service is present in their village. Hence, even when they have stated that the service was “absent” they ranked the service “important” and even “very important”. On ranking, some of the interviewed had difficulties in differentiating between “very important” and “important”. The result of the perception of the households on the importance of mangrove is presented below, for each category of the mangrove services.

Mangrove as timber and building material provider

Almost all the households interviewed said they were aware that mangroves provide timber and building material and ranked the services as very important to important in their livelihood. Very few said the service was not present, and these were the household living far away from mangrove areas, and perhaps on answering the service is absent they may meant that it is absent in their village. Nevertheless, all ranked the service important (Figure 6.4(a)). Overall nearly 95 percent of the interviewed said that they are aware that mangrove provide timber and building material and ranked the service as very important to in their livelihood (Figure 6.4(b)).

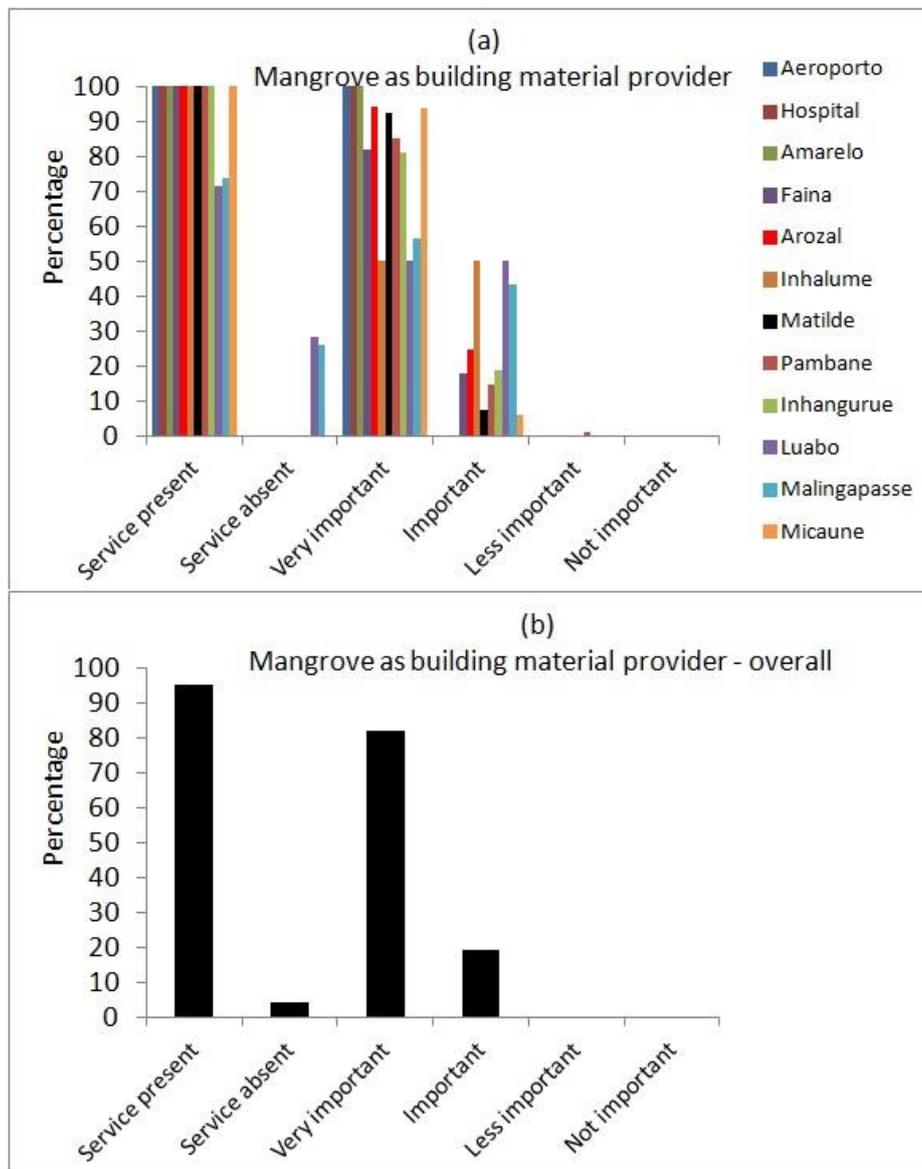


Figure 6.4. Household perception on the mangrove as provider of timber and building material in the Zambezi Delta.

Mangrove as provider of firewood and charcoal

On answering whether the mangrove provide firewood and charcoal, almost all the interviewed answered positively and ranked very important (Figure 6.5(a)). The few ones who said the service was not present they may have meant that there is no mangrove in their village, but almost all ranked the service as very important. Overall the interviewed recognized the fact that mangrove provide firewood and charcoal and said the service is very important to their livelihood (Figure 6.5(b)).

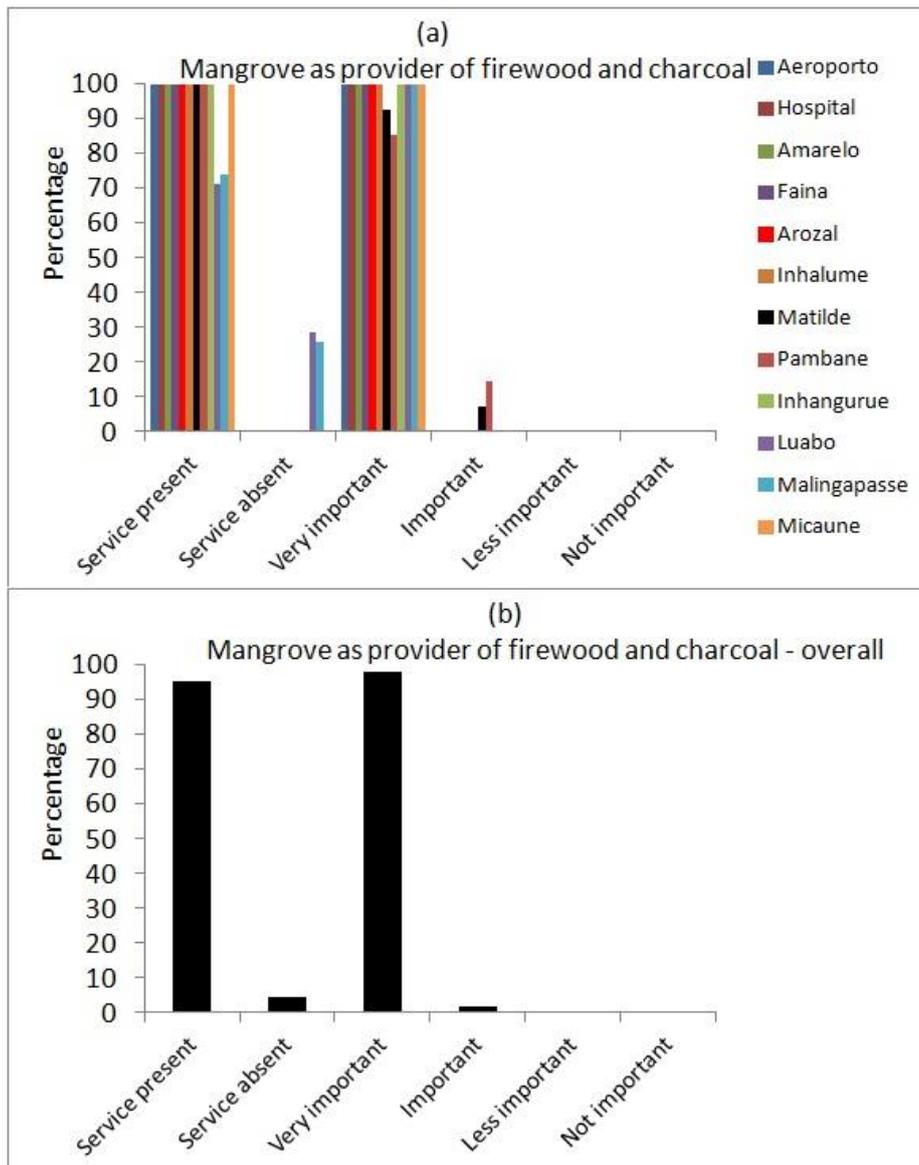


Figure 6.5. Household perception on the mangrove as provider of firewood and charcoal in the Zambezi Delta.

Mangrove as food provider

On answering whether the mangrove provide food, meaning mainly fisheries products, the interviewed answered that the services were present and ranked it of very important to important (Figure 6.6(a)). However, very few, particularly those living away from mangroves, said they were not aware that mangroves provide food. Perhaps, some of these may have meant that the service is not present in their villages, since there are no mangroves. On the other hand, very few have said the mangrove is less important and even not important. Overall, however, most of the interviewed were aware that mangroves provides food and the service was very important to important to their lives (Figure 6.6(b)).

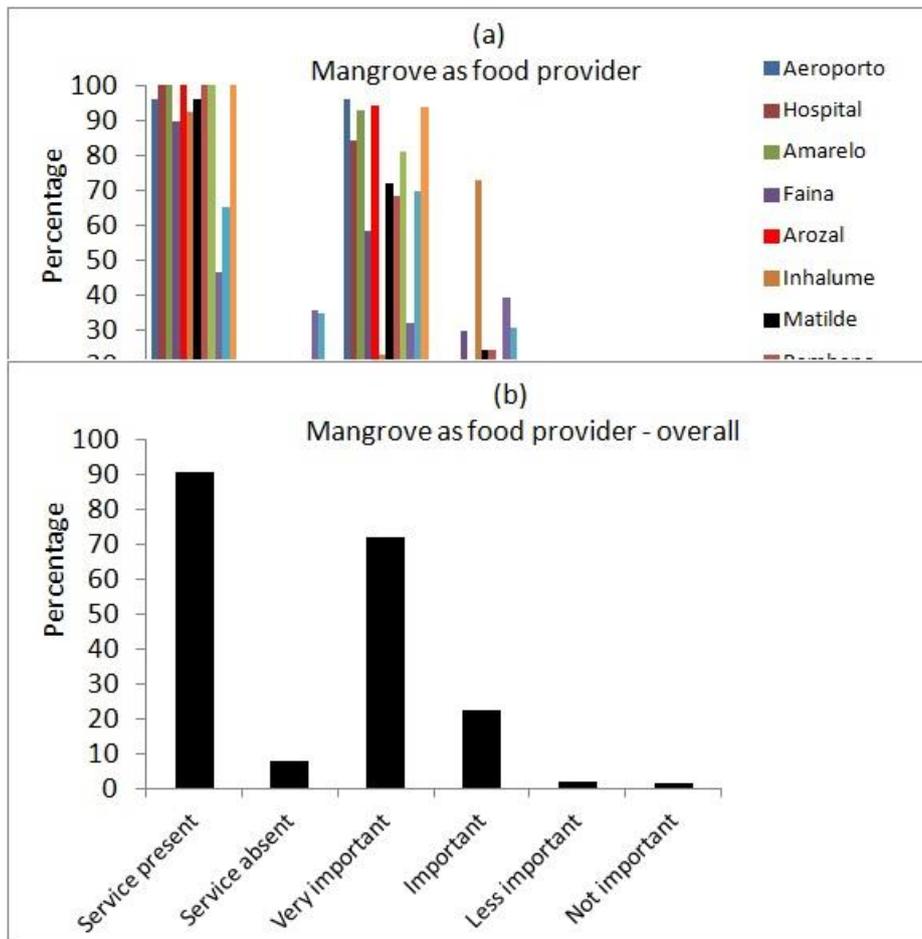


Figure 6.6. Household perception on the mangrove as food provider in the Zambezi Delta.

Mangrove as fish provider

The question meant to assess whether the interviewed were aware of the ecological role of mangroves, i.e. habitat and nursery - breeding, spawning and nursery habitat for commercial fish species, by asking specifically if they know that the production of fish, crabs, shrimp and snails are related to mangrove. On formulating the question it was assumed that the previous question (mangrove as food provider) could not have been clear enough. The answers obtained showed clearly that the interviewed were well aware that fish production is strongly linked to mangroves (Figure 6.7). Relatively low ranking was recorded for snails where some interviewed thought it was not related to mangrove. Perhaps that could result by the fact that snails are not widely captured and trade as fish, crab and shrimp.

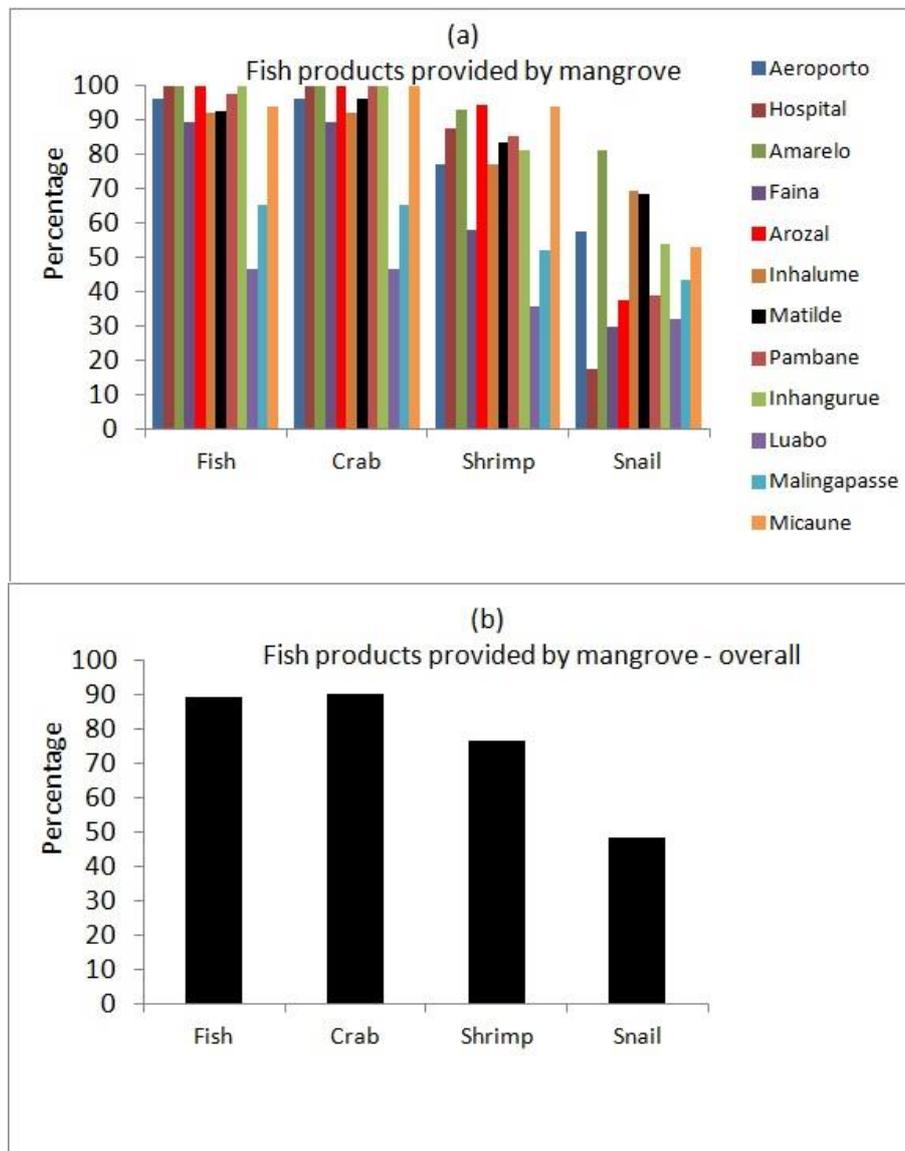


Figure 6.7. Household perception on the mangrove as fish products provider in the Zambezi Delta.

Mangrove as honey provider

The households were asked if they knew they could keep bees and produce honey in mangroves. There was a significant proportion of households aware of the fact that they could practice beekeeping in mangrove, and a quite large proportion of households who were not aware of such practices (Figure 6.8). Though some could have said the service was absent meaning they are not currently practicing it. The households from Malingapasse were very positive and enthusiastic about beekeeping as it is a known practice for them and they practice it in the terrestrial forest. Overall about 60% of the interviewed households in the entire Delta were aware of the possibility of practicing beekeeping and ranked the activity very important to important in securing their livelihood. Quite a significant proportion, about 40%, of the households said the service was absent and ranked less important to not important in their livelihood (Figure 6.8(b)).

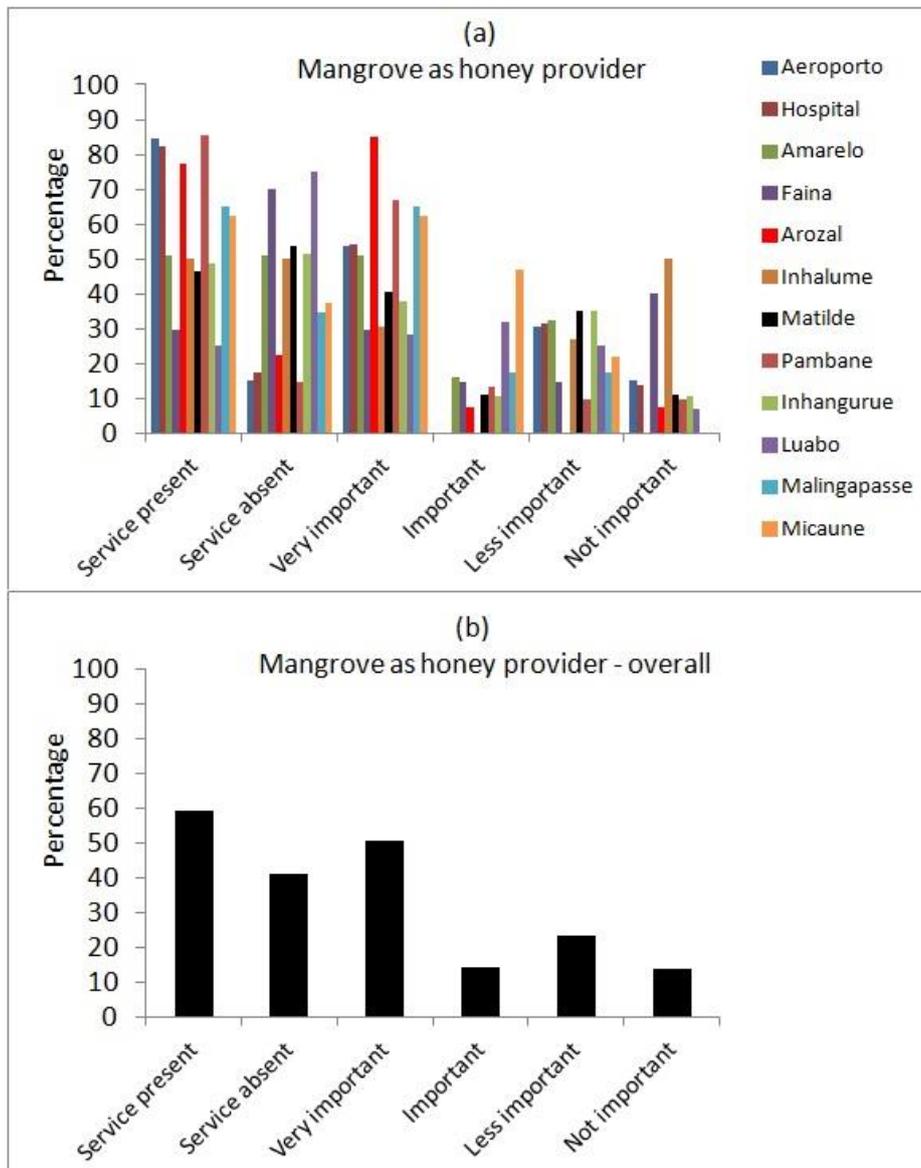


Figure 6.8. Household perception on the possibility of practicing beekeeping and producing honey in mangroves in the Zambezi Delta.

Mangrove as coastal protector

The question meant to assess whether the interviewed were aware that mangroves can protect the coast against erosion and storms. Most of the interviewed showed that they were well aware about the protective role of mangrove, and ranked the service as very important to important (Figure 6.9). The few interviewed that said the protective mangrove was absent could be assumed they meant that there is no erosion or serious erosion in their village and, perhaps for the same reason may have ranked the protective role of mangrove as less important. Overall the interviewed were well aware that mangroves provide protection against erosion and buffer to storms and ranked the service as very important to important to their lives (Figure 6.9(b)).

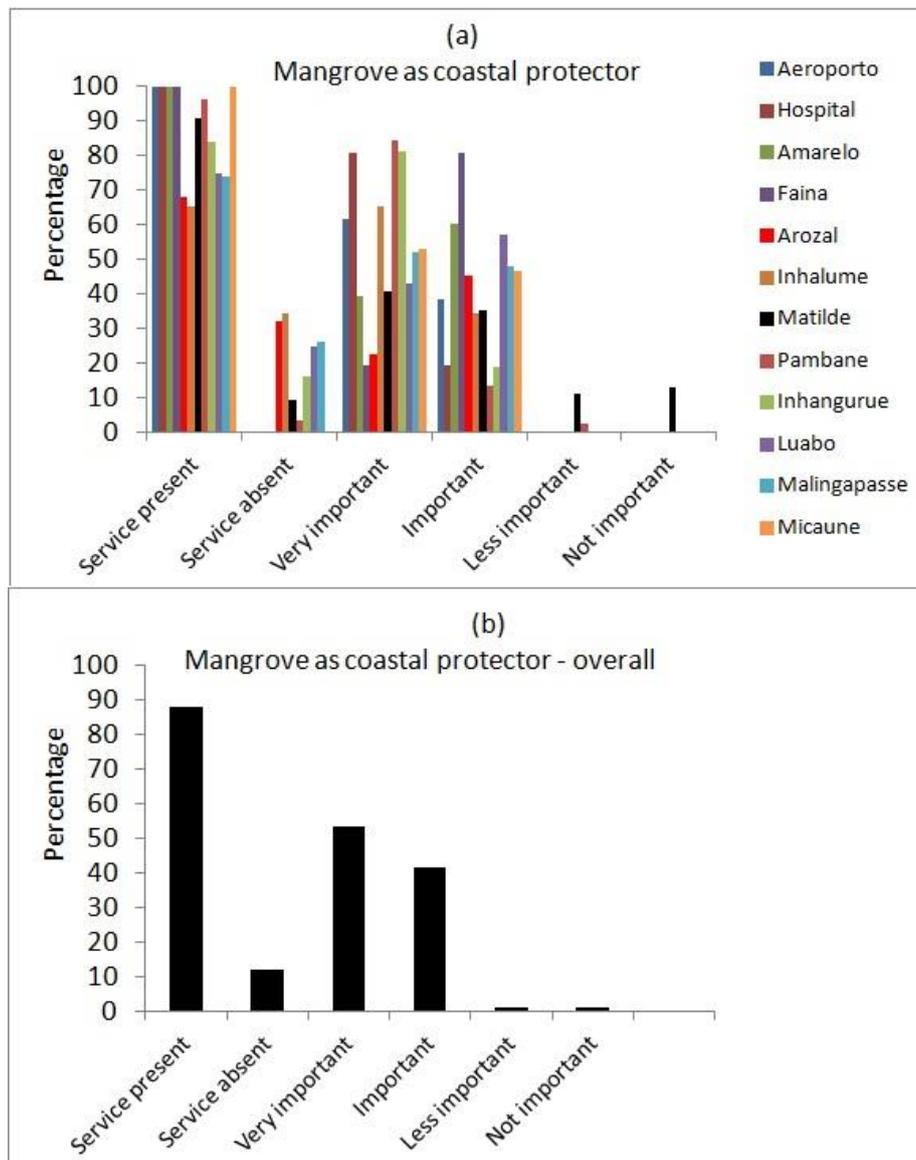


Figure 6.9. Household perception on the role of mangrove on protecting the coast against erosion and storms in the Zambezi Delta.

Mangrove sites used for cultural and ritual ceremonies

Mangrove sites are used for traditional rituals, where the elders go and pray for the gods and pled for blessing and for luck and higher production in fisheries. Large proportion of the households interviewed was not aware of the fact that mangrove sites are used for such rituals (Figure 6.10). These could be explained by the fact that the ceremonies are not held every year, and when it occurs it involves the elder people. Overall nearly 70% of the households interviewed said the service was absent and ranked less important to not important, and about 30% of the interviewed considered the service present and ranked the important to very important (Figure 6.10(b)).

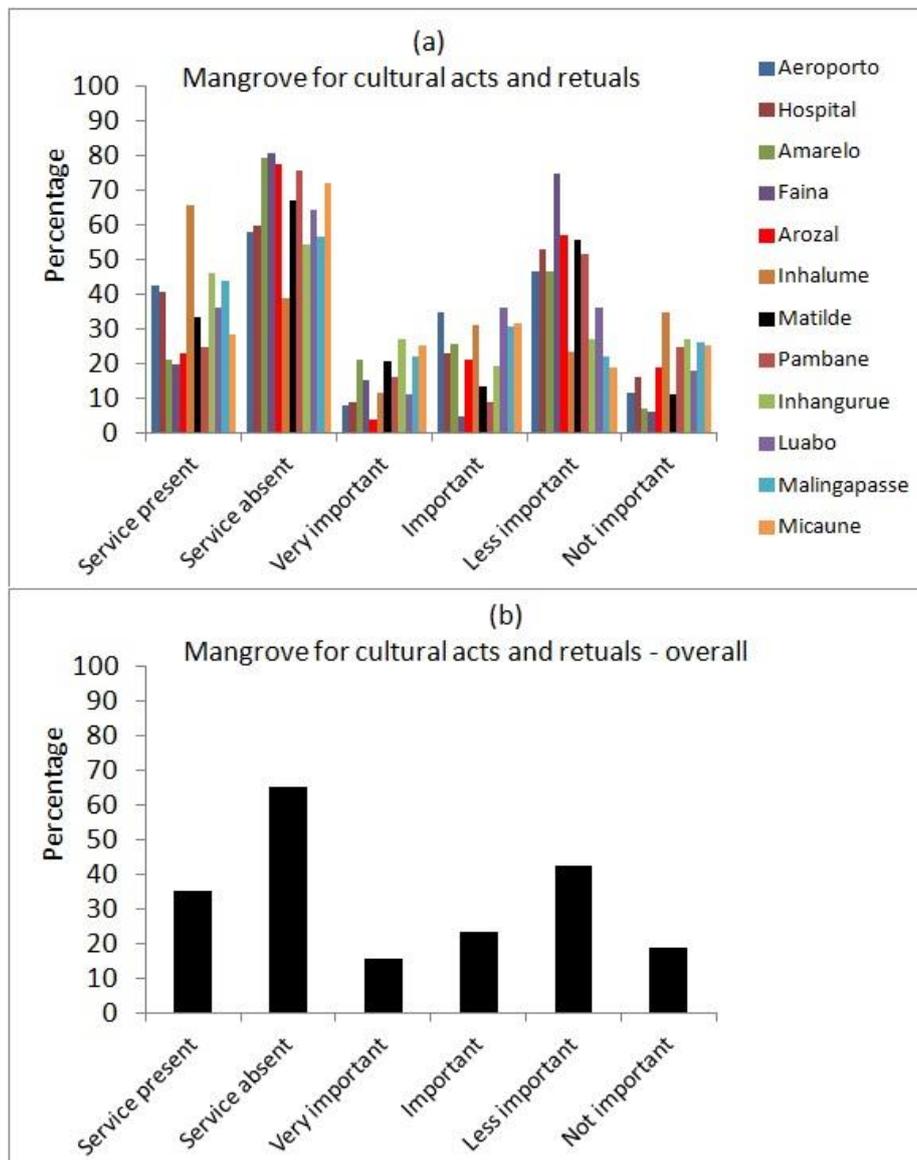


Figure 6.10. Household perception on the use of mangrove sites for cultural and traditional rituals in the Zambezi Delta.

Mangrove as medicine provider

Asked if they were aware that mangrove are source of medicine most households were positive and ranked the service as very important to important. There were, however, a large proportion of households who were not aware of the medicine obtained from mangrove, and perhaps for that reason ranked the service as less important to not important (Figure 6.11). Perhaps using the same reasoning as that for cultural and rituals services in mangrove that are carried by elder people, the medicine are used by traditional healers, and so fewer people are aware of that use. They said that they obtain medicine to cure different diseases, such as wounds, infections, dysenteries and constipation. Overall about 70% of the household interviewed said the services was present and ranked very important to important, and about 30% of the interviewed considered the service absent and ranked the less important to not important (Figure 6.11(b)).

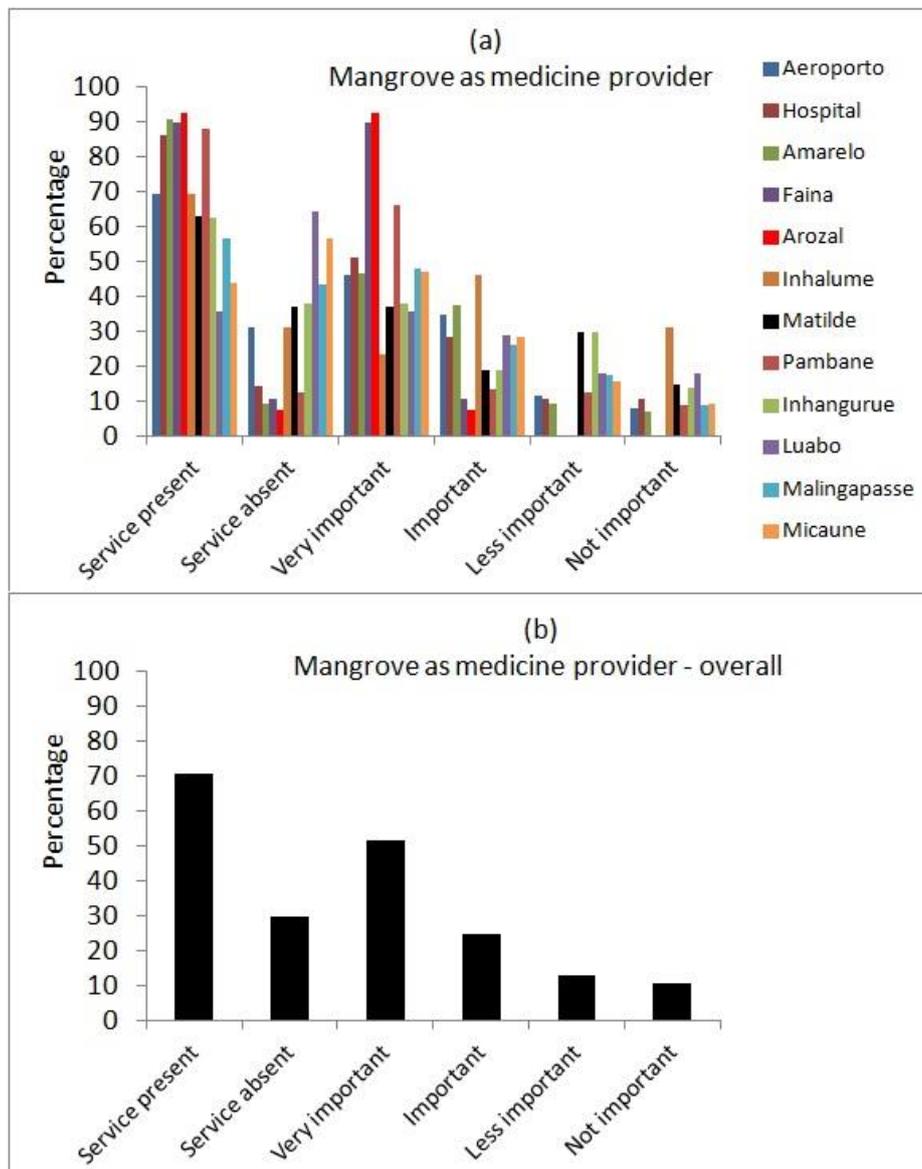


Figure 6.11. Household perception on the mangrove as source of medicine in the Zambezi Delta.

6.6. Perception of the interviewed households on the willingness to plant mangroves

Given the fact that there is a general awareness on the importance of mangrove on provision of goods and services, services that span from ecology to coastal protection the households were asked whether they are willing to contribute in labor or monetarily for mangrove restoration. The result is presented in Figure 6.12. Most of the interviewed agreed to contribute in labor for planting mangrove, particularly those living in regions suffering from erosion such as the Chinde Village (Amarelo, Hospital, Aeroporto, Fina, Arrozal). People from these villages offered voluntarily to combat erosion and plant mangrove if the government offers the necessary working equipment and material, and reported similar initiatives in which they participated in the past. However few people living in regions that are not suffering from erosion or away from mangrove said they would contribute in labor to do in their free time, i.e. after day-to-day work for their livelihood. Very few said they would not contribute for mangrove restoration because they believe mangrove grows

naturally. Overall nearly 90% expressed their willingness to contribute for planting mangrove in the entire Zambezi Delta.

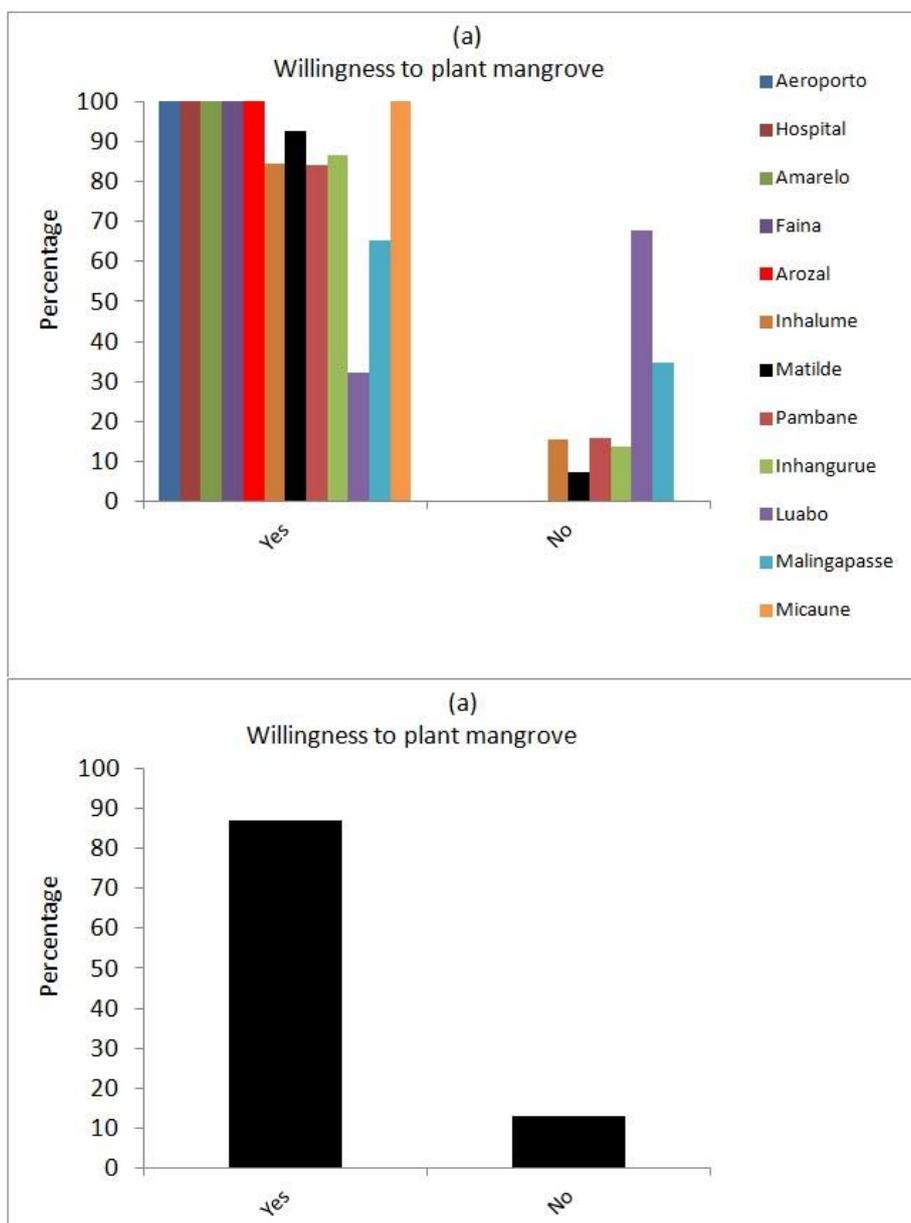


Figure 6.12. Willingness to contribute to restore mangrove in the Zambezi Delta.

7. Results - Household Income

Based in the interview results, the census of 2011 and strategic planning of 2005 of the Districts of Chinde and Marromeu, the major livelihood activities identified in the Zambezi Delta and related to mangrove ecosystems were as follows:

- Agriculture;
- Fisheries;
- Mangrove forest product harvesting.

Agriculture is mainly practiced for subsistence while fisheries and mangrove forest products are used for income generating. During the survey it was observed that direct mangrove harvesting is mainly practiced by women while men go for fishing. The primary activity of women is agriculture, and mangrove harvesting is practiced to supplement the house income. Table 7.1 presents the monthly production per household of the mangrove products, poles, timber, firewood and charcoal, those obtained from cutting mangroves and the fisheries, products derived for mangrove ecosystem services, and obtained by conserving mangroves.

Table 7.1. Monthly production per household.

Location	Direct harvesting of mangrove (quantity)		Indirect use of mangroves (resources obtained from ecosystem services) (kg)		
	Bags of charcoal (0.105 m ³)	Poles (unit)	Shrimp	Crab	Fish
Chinde - Aeroporto	20				
Chinde - Hospital	18	288	7,684	75	11,074
Chinde - Amarelo			175	40	750
Chinde - Arrozal	108	175	288	200	421
Chinde - Inhalume	50	75			
Matilde		554			487
Pambane	230	116		64	678
Inhagurue	120	86	140	50	350
Luabo					250
Malingapanse					138
Micaune - Tivarone					
Average	91	216	2,072	86	1,769

7.1. Gross household income

The gross monthly household income is presented in Table 7.2. It is clear that the resources provided by the ecosystem services render more income to households than the direct harvesting of mangrove. Using exchange rate of 30MZN per US\$ we obtained that charcoal render about US\$290 per household per month, poles for building render about US\$180 per household per month while the shrimp, crabs and fish render US\$449, US\$211 and US\$443, respectively. It should be noticed that crabs have the potential to provide more income per household if markets are provided. Currently there are two Tanzanian citizens and one Chinese citizen in the Delta devoted to crab trade. These buy and export about one ton of crabs per month each. Figure 7.1 show a picture of a Chinese buying crab in the Delta to export to China. The mangrove related resources contribute significantly to the wellbeing of coastal population considering the fact that the average GDP per capita in Mozambique (from 1980 until 2015) was estimated at US\$267.34, with high of US\$511.47 USD recorded in 2015 and the low of US\$130.44 recorded in 1986.

Table 7.2. Gross monthly income per household.

Location	Income obtained from direct harvesting of mangrove (MZN)		Income obtained from ecosystem services (MZN)		
	Charcoal	Poles	Shrimp	Crabs	Fish
Chinde - Aeroporto	3,047				
Chinde - Hospital	3,750	12,533	30,536	3,500	57,963
Chinde - Amarelo			10,250	3,750	9,000
Chinde - Arrozal	5,233	5,264	8,850	15,000	4654
Chinde - Inhalume	7,500	1,500			
Matilde		9,418			18,409
Pambane	14,500	2,250		4,542	6,803
Inhagurue	18,000	1,720	4,302	5,000	5,830
Luabo					2,500
Malingapanse					1,380
Micaune - Tivarone					
Average	8,672	5,448	13,485	6,358	13,317



Figure 7.1. Amangrove crab trader from China, Pambane, Chinde, Zambezi Delta, October 2016.

7.2. Net household income

Net household income for charcoal production

The estimate cost of the charcoal production is presented in Table 7.3. As obtained during the interviews, the production involves two men, working on average two stoves per month totaling 40 hours of work per month, from which they spend 20 hours in cutting and transporting the wood, 15 hours preparing the stove and 5 hours pilling and selling the charcoal. The labor is estimated at MZN20 per person and per hour. The investment is composed by one saw, two blades and two axes at the cost of MZN500, MZN150 and MZN300, respectively, and the lifetime of this equipment is estimated at about 3 years. They use about 11 m³ of wood and produce about 1.76 m³, equivalent to 32 bags of charcoal. Hence the production cost is estimated at MZN1,638 per 32 bags of charcoal, from which MZN38 is the depreciation of the capital and MZN1,600 is the labor or running costs for the production of 32 bags. Considering the price of MZN150 per bag, the net income for the gross income for 32 bags is MZN3,162, which divided per 2 persons, becomes MZN1,581 average income per household, equivalent to US\$53 per household per month.

Table 7.3. Estimate of the net household income per month for charcoal production.

Item	Quantity	Unit value (MZN)	Amount per month (MZN)
Labor (man/month)	2 men x 40 hours	20	1,600
Capital cost:			
1 saw		500 for 36 months	14
2 blades		150 for 36 months	8
2 axes		300 for 36 months	16
Total production costs			1,638
Average production per month	2 x 16 bags	150	4,800
Net income			3,162
Net income per household			1,581

Net household income for mangrove poles production

The estimate of the cost production of poles is presented in Table 7.4. The information was also obtained from the interviews. The production involves one man, working on average 140 hours per month, and producing on average 50 to 500 poles per month, depending on the size. The labor is estimated at MZN20 per person per hour. The investment is composed of one saw, one blade and one axe at the cost of MZN500, MZN150 and MZN300, respectively, and the lifetime of the equipment is estimated at about 3 years each. The production cost is estimated at MZN2,826 per month, from which MZN26 is the depreciation of the capital and MZN2,800 is the labor or running costs per bag. Considering the average production per household per month of about 200 poles at average price of about MZN30 per pole, the net income is estimated at MZN3,174 per household per month, equivalent to US\$105 per household per month. Table 7.5 presents the summary of the production cost of poles and charcoal and the net household income per month.

Table 7.4. Estimate of the net household income per month for the pole production.

Item	Quantity	Unit value (MZN)	Amount per month (MZN)
Labour (man/month)	1 man x 140 hours	20	2,800
Capital cost			
1 saw		500 for 36 months	14
1 blade		150 for 36 months	4
1 axe		150 for 36 months	8
Total production costs			2,826
Average production 200 bags		30	6,000
Net income per household			3,174

Table 7.5. Summary of the estimate of the production cost and net household income per month for the mangrove poles and charcoal production.

Item	Amount per month (MZN)	
	Charcoal	Poles
Labor (man/month)	800	2,800
Capital costs	19	26
Total production costs	819	2,826
Average gross income	2,400	6,000
Net income per household per month	1,581	3,174

Net household income from fisheries

The information on the production costs and net income was provided by the Fisheries Department responsible for small scale fisheries, former IDPPE. The estimate of the production cost of fish is presented in Table 7.6. The production involves on average 10 men, working on average 90 hours per month, as it depends on tides. The labor is estimated at MZN30 per person per hour. The capital cost involves seines and boats at different costs (Table 7.7) and the labor, per fishing gear, which takes between 3 to 22 people. Hence, the average production cost is estimated at MZN26,619 per month, of which MZN4,344 is the depreciation of the capital and MZN22,275 is the labor. The monthly gross income, involving 10 fishermen, is estimated at MZN122,369 for fish and about MZN150,620 for shrimp, as it includes small shrimp. This gives the net monthly income for the 10 fishermen of MZN95,750, for fish and MZN128,345 for shrimp, which then giving a net income of MZN9,575 per household per month from fish and MZN12,400 for shrimp, equivalent to US\$319 and US\$413 for fish and shrimp, respectively. In relation to crabs, the investment is a blade or a hoe at the cost of MZN150, and involves one person, working 80 hours a month, at the rate of MZN20 per hour, producing about 500 kg of crabs at the cost of about MZN75 per kilogram. Hence the production cost is estimated at MZN1,750. The gross income per household per month is estimated at MZN7,500, thus the net income per household per month is MZN5,750, equivalent to US\$192 (Table 7.8).

Table 7.6. Estimate of capital costs for fisheries production, fish and shrimp.

Fishing gear	Capital cost (MZN)	Lifetime (years)	Monthly cost (MZN)
Beach seine	372,000	5	6,200
Estuarine seine	170,000	6	2,361
Bottom gillnet	156,500	2	6,521
Surface gillnet	76,670	6	1,065
Boats			
Canoe	10,000	6	139
Wooden boat type Moma	57,000	10	475
Average			2,794

Table 7.7. Estimate of running costs for fisheries production, fish and shrimp.

Fishing gear	Number of people involved	Hours of labour per person month	Unit cost per person (MZN) per	Monthly cost (MZN)
Beach seine	22	90	30	59,400
Estuarine seine	5	90	30	13,500
Bottom gillnet	3	90	30	8,100
Surface gillnet	3	90	30	8,100
Average				22,275

Table 7.8. Summary of the estimate of the production cost and net household income per month for the fisheries production.

Item	Amount per month (MZN)		
	Shrimp	Crab	Fish
Labour (man/month)	2,228	1,600	2,228
Capital costs	434	150	434
Total production costs	2,662	1,750	2,662
Average gross income	15,062	7,500	12,237
Net income per household per month	12,400	5,750	9,575

Table 7.9 compares the monthly household income from the mangrove and from the fisheries products. It is clear again, that people gain more from the fisheries products than from timber and charcoal. Hence, the mangroves worth more to people conserved than destroyed.

Table 7.9. Comparison of the monthly household income from mangrove and from fisheries products.

Item	Amount per month (MZN)				
	Charcoal	Poles	Shrimp	Crab	Fish
Labor (man/month)	800	2800	2,228	1,600	2,228
Capital costs	19	26	434	150	434
Total production costs	819	2,826	2,662	1,750	2,662
Average gross income	2400	6,000	15,062	7,500	12,237
Net income per household per month	1581	3,174	12,400	5,750	9,575

8. Threats and drivers to mangrove and associated resources

The threats to the mangrove ecosystem could be broadly grouped into two categories: Natural and Anthropogenic. In the Zambezi Delta the identified natural threats are mainly climate change and cyclones; and the anthropogenic threats include tree cutting for fuelwood and for building material and artificial river runoff.

8.1. Climate change induced threats

Climate change induced threats influence mainly the physical factors. Mangroves require desired physical conditions for their survival, whose main parameters are water volume, temperature and salinity. Mangrove forests are marine wetland vegetation, adapted to wet soils, saline habitats, and periodic tidal inundation. They are associated with tidal swamps. The swamps may be connected, by a single or a limited number of tidal inlets, either to an estuary, lagoon, bay or directly to the coastal continental shelf. These tidal inlets, responsible for the drainage of the swamps, are also called mangrove creeks. The swamps are regularly influenced and disturbed by seasonal freshwater and semidiurnal tidal flooding, so the water masses of the mangroves may be brackish. The salinity has large time scale variability: diurnal or semidiurnal as well as bi-weekly because of the tides, and annual due to the change from dry to rainy seasons. The swamp is, in general, shallow and may remain dry for several hours during low water and during neap tides. The upper reach of the swamp may only be flooded during the highest spring tides. There may be a sill at the mouth of the mangrove creek. This may be a result of sand movement, due to the action of the waves along the beach. The height of the sill may determine the extent to which, and the time span that, the mangrove may be flooded.

Hence, the most important physical processes associated with mangrove swamps are those brought by climate and tides, as they primarily regulate the factors that most control the productivity and transport of the nutrients. Since the mangroves are located in the intertidal zone, at the interface of sea and land, one of the key physical processes are those related to mixing between sea and coastal waters, flushing and export of the coastal water to the adjacent seas, heat and cooling.

Climatologically the mangroves are associated with wet lands, higher air moisture content and warm climate. These conditions are best found in tropical regions. Heavy tropical rain and the subsequent river flow supply the swamps with nutrients, and dilute the water within the swamp, contributing in this way to keep the salt balance. The supply of freshwater to the swamps may also occur through the ground reservoirs, when available.

Given these conditions, the main climate threats identified in the Zambezi Delta are floods and storms, mostly caused by cyclones. The river floods and wave action may cause infilling and blockage of the mangrove creeks and mangrove roots with sediments. Aerial roots are a common adaptation of mangrove trees to their saline wetland habitat, allowing root respiration in the anaerobic substrate. However, excess input of sediment to mangroves can cause death of trees owing to root smothering (Ellison, 1999). Further, although mangroves are adapted to seasonal freshwater flooding, excessive freshwater can cause death of mangroves. On the northern margin of the estuary, adjacent to Chinde Village, excessive freshwater caused by flooding may lead to super-dilution of water in the swamps, causing disturbance in the regular development of the mangroves, which depending on the severity, may cause death of mangroves by salt shortage stresses and by siltation, which again covers the mangrove roots. Figure 8.1 shows a mangrove that died by excessive freshwater and flooding in

the northern margin of the estuary in Chinde Village. Apparently, the recovering from excessive freshwater and flooding seems to be a rather slow process, as the new forest should have set itself in the dense mangrove forest. Along the beach storms and waves push sand dunes and sediments towards the mangroves and cover the mangrove roots, causing the death of the trees. The recovering in the circumstances of storms, however, is relatively fast, as the sand dunes set by storms, cause enabling environment for mangrove seeds to fix and grow in a new forest.



Figure 8.1. A dead mangrove tree by excessive freshwater and flooding in the northern margin of the estuary in Chinde Village. Chinde, October, 2016.

8.2. Anthropogenic threats

Artificial river runoffs by the dams alter the natural seasonal cycle of rivers, causing either reduced or increased amount of water reaching mangrove forests, changing the salinity level of water in the forest. If salinity becomes too high or too low the mangroves cannot survive. Further, the dams trap sediments, causing sediment deficit which may increase erosion. The effects of the hydroelectric dams, in particular, is characterized by disturbances in the seasonal pattern of the runoff. Since they should produce electricity throughout the year, including in the dry season, they allow increased runoff during the dry season than should be naturally, and reduce the flood runoff during the wet season to keep water in the reservoir, resulting in a reduced wet season runoff. The artificial flows contrast with natural ecological cycles of ecosystems. Gammelsrød (1992) found a positive correlation between the shrimp production in Sofala Bank and the Zambezi runoff during the flood season, which is a clear evidence that an increase in the discharge during that period may enhance the shrimp production, and found a negative relationship between the catch and the dry season runoff, though weaker, it indicates that the runoff should be kept at minimum during the dry season in order to enhance the shrimp production. In addition, there are spots of mangrove deforestation as a result of excessive mangrove harvesting for timber, building material, firewood and charcoal production.

9. Policy recommendations and options for sustainable mangrove use

This study aimed at clarifying the different values and perspective of the ecosystem services of mangroves in the Zambezi delta and their significance to the household income, with a view to providing evidence for fostering conservation and sustainable development plans. Although the study indicated that the levels of exploitation of mangrove and associated resources is sustained, it also indicated that, given the actual trends in human growth, there is a potential for negative trends if sustainable exploitation of mangrove trees, fisheries, including crabs are not implemented. Further, the study showed that mangroves render more to people if conserved, thus, exploiting sustainably the associated resources than when exploiting the mangrove trees for firewood, charcoal and building material, all of which involve cutting of mangroves. Hence, it is strongly recommended the promotion of alternative livelihoods to cutting mangroves. In addition, the study showed the negative downstream effects of the hydroelectric dams. This outcome does not imply that the dam should not be developed, but instead calls for maintaining and magnifying natural flow regimen, taking advantage of the fact that the river is regulated.

9.1. Options for sustainable harvesting of mangrove

The stands of mangroves in the Zambezi Delta still allows for sustainable harvesting. Most of the mangrove forests are highly dense and with many old, tall and thick trees that are only suitable for timber production. On the other hand the forest management requires harvesting of old trees to allow for regeneration of new trees, particularly in an environment where the tree density is high such as in mangrove forests.

Rough estimates of the allowed amount for sustainable mangrove forestry are as follows: the allowed commercial size would be 7.5 m height, 2.5m perimeter. The trees would attain that size in about 10 years and 13 trees of that size would provide 20 bags of charcoal. The ideal forest density would have about 1800 trees. Hence the amount of trees allowed per month would be 13 trees, providing an income of US\$100 per hectare per month or US\$1,200 per hectare per year, an amount which is about 4 times the average GDP per capita. If a household is assigned one hectare of mangrove to explore, then the total mangrove area of the delta, estimated at 281,074 ha, would benefit 281,074 households. Hence, it is here suggested that a household be assigned a hectare of mangrove to explore sustainably. The potential villages suggested to benefit for such indicatives, in the pilot phase, are Bairro Hospital and Bairro Amarelo in Chinde Sede and Pambane, where currently there is a strong mangrove harvesting for timber, fuelwood and charcoal.

9.2. Suggested alternative livelihoods

The promotion of alternative livelihood to cutting trees is urgently needed. Based on the household surveys the identified livelihood alternatives for mangrove cutting are:

- Agriculture;
- Fish processing and trade;
- Cage aquaculture;
- Crab fattening and trade and
- Bee keeping.

Agriculture

The region of Chinde has potential for commercial agriculture. In the past there was a rice irrigation system working in Luabo and Nhacatima such as the irrigation of Sombo. These irrigation systems use tides, and so, are sustainable. Hence, it is strongly recommended that local government should promote income generating agriculture rehabilitating the tide driven irrigation systems of Sombo, and providing support in agriculture supplies. In principle, income generating agriculture could be implemented in all the villages.

Fish processing and trade

Most of the fish products in Chinde, apart from crab and shrimp, are sold dry. The drying facilities are poor, often exposed to the air and to weather factors, and so, often losing quality. Hence, it is strongly recommended to the local government to support the fishermen and traders by establishing fish processing and conservation facilities, as to enable adding value to the fish products. Fisheries activity is practiced in almost all the villages in the delta. However, most fish is captured by fishermen of the Bairro Hospital, Bairro Amarelo and Bairro Aeroporto, in Chinde Sede and in Matilde and Pambane. Hence, fish processing facility could be established in any, if not in all these villages. The government is currently building a fridge in Matilde for fish products. Further, there is a need to support the small entrepreneurs in fish trade to access financial credits and markets. This activity would contribute to reduce post-harvest losses, add value to fish products and increase income. Ultimately, may contribute to reduced pressure on the natural stocks and ecosystems.

Crab fattening and trade

Among the marine crabs, mud crab is considered a very expensive seafood delicacy all over the world. The common species is *Scylla serrata* which can grow in cages with no destruction of mangroves, at stocking density of 5,000 ha⁻¹, and growing up to 800-900g. The technology involves the construction of small cages with individual cells which are then stocked with lean crabs, weighing at least 100 g (if female native crabs) or 300 g (if female giant crab). Males weighing 200 g (if native) or 350 g (giant crab) may also be stocked individually in the cage cells. Fattening can take 15-30 days. Mud crab fattening has become highly remunerative as reported by a number of farmers (DA, Region VI, 1988; Kuntiyo, 1992).

In Mozambique there is great potential for mud crab *Scylla sp.* trading. There are companies that export crabs to Asia. In Chinde there are three foreigners dedicated to crab trade. Currently crabs are collected from the wild, but there is a potential for crab fattening in cages. Hence it is strongly recommended that government promote and foster entrepreneurship for crab fattening and trade. Similarly to fish trade group the entrepreneurs in crab trade also need to be supported to access financial credits and markets. Crab fattening could be implemented in the same villages suggested for installation of fish processing facilities, since they also have excellent facilities for mariculture in cages. They are as follows: Bairro Hospital, Bairro Amarelo and Bairro Aeroporto, in Chinde Sede and in Matilde and Pambane. This activity would contribute to increase the income and to reduce pressure on the natural stocks and ecosystems.

Beekeeping

Beekeeping can be a thriving business. Mangrove forests have the potential for honey production throughout the year. Beekeeping is a lucrative business. It can provide employment, income and economic security for the farm family and others in rural areas. It requires a minimal investment to start-up, and does not require complex technologies and techniques to maintain. It can be built from traditional knowledge and embedded in local culture and habits. In addition to honey, bees provide for other marketable products such as wax, pollen, royal jelly, propolis, venom, etc. Further, bees may contribute to crop production through pollination process (Mariki, 2007). Hence, the support needed to promote beekeeping in the delta would be in technology for honey processing and also in access to credits and markets. This activity could be implemented in the following villages: Bairro Faina and Bairro Arrozal, in Chinde Sede, in Matilde, Pambane, Inhagurue and Malingapasse. This activity would contribute to increase income and to conservation of mangrove forest as it is the foothold of honey production.

9.3. Alternative building material to mangrove poles

Chinde, and almost throughout the country there are alternatives for building with mangrove poles. The viable building material is clay, which is abundant in alluvial valleys such as in Zambezi Delta. With clay it is possible to build bricks and construct improved solid houses. Brick houses are common in Chinde. Figure 9.1, present a brick house in Chinde. The government has adopted the policy of promoting brick houses where clay is available as a means to reduce risk of the vulnerable people to cyclones.



Figure 9.1. A typical brick house in Chinde, Chinde, Zambezi Delta, October 2016.

9.4. Sustainable management of the dams

The managers of the Cahora Bassa hydroelectric dam are requested to manage the dam in such way for the flow to mimic the natural seasonal cycle of the ecosystem, allowing for high and low flows during the wet and dry season, respectively. Such compromise may result in a decrease in power production during the dry season and may attempt to water security in the view of climate change. This is the risk that should be faced; however, the sustainability of ecosystems may render more to the countries' economy than that provided by the electricity.

10. Discussion

The mangroves in the Zambezi Delta are well preserved with stands of old, tall, wide and dense mangrove trees, despite few small spots of deforestation. The present study showed evidences that there are possibilities for sustainable mangrove harvesting in the delta. Mangroves in the delta are currently explored for charcoal, firewood and timber for building. While charcoal provides significant household income, the timber production could provide a lot more, for mangrove trees produce dense, valuable wood, which is resistant to decay and to the impact of termites. Sustainable harvesting of mangroves has been practiced over 120 years in parts of Malaysia and Bangladesh (Brander et al., 2012). However, for sustainable harvesting there is a need to establish and maintain a sustainable mangrove management plan. This study recommends a mangrove management system in which the allowed tree size for charcoal production would be 7.5 m height, 2.5 m perimeter, and the allowed harvest would be 13 trees per month per hectare, providing 20 bags of charcoal per month per hectare, which provides an income of US\$100 per month per hectare. This harvest would result in a harvest of 156 trees per hectare per year, providing 240 bags of charcoal, earning US\$1,200 per hectare of mangrove per year. Such harvesting could be trusted to a household, and considering the total area of mangroves in the delta estimated at about 37,034 ha, it would benefit 37,034 households. The suggested harvest of 156 trees per hectare per year is low, however, it would sound sustainable considering an ideal forest density of 1,800 trees per hectare and a rotational period of 10 years. Gan (1995), on the other hand, considered a rotation cycle of 30 year, with an average yield of 17.4 t ha⁻¹ yr⁻¹, which would be appropriate for timber production. Most of the mangrove trees in the delta are over 30 years of age and with the sizes over 30 m height and 2 m perimeter.

It should be noted that for a healthy forest there is a need to cut old trees to allow for new trees to develop, the selective harvesting (Kairo et al 2011 and 2002). However, mangrove forests have particular features which make them different from other forests as they are highly dense making it difficult to penetrate and do selective cutting. As a result, people tend to cut them in sequence, clearing the forest as they go along. Further, mangrove trees tend to attain the same size at the same time, prompting to be harvested all at the same or making no choices. Of particular interest is the way people in the delta cut mangrove trees; they cut them at some height, about 40-100 cm, above the ground, which allow for easy regeneration.

In the present study the protective value of mangroves was estimated considering the erosion and the value of infrastructures at risk, thus, by damage avoided method. The erosion is observed in Chinde village, along 1.5 km extension of the coastline, and it is said to be due to the cutting of mangrove along that strip for building. Now, the coast is exposed in such way that reforestation would require setting up a protection against waves and currents, to allow the mangrove seeds to settle. In the area along the coast, however, storms build up sand dunes, parallel to the coast, and in the subsequent valleys enabling a good environment for mangrove seeds to settle, and thereon new mangrove forests have been established. The local people are well aware of the protective value of mangroves against erosion, and are willing to contribute for restoration and conservation. The protective value of mangrove estimated at US\$ 20,000.00 per hectare of mangrove per year, in the present study is higher compared to the value obtained by Rao *et al* (2015), which was in ranged 0.4- US\$2,529.9 ha⁻¹ year⁻¹, and was low compared with the values obtained by Koch *et al* (2009) which were in the range 71,496.01- 159,405.72 US\$ha⁻¹ yr⁻¹ for different mangrove species and tree density. Perhaps the difference may be justified by the valuation method used, as in the present

study it was used the method of damage avoided, which consists in evaluating the infrastructure at risk, which in turn, depends on the infrastructures available and their value on the local market price. The mangrove in the delta do protect the cost against the storm, which could be depicted by tilt of the trees along the coastal strip, however, in the present study it was not possible to estimate the value because there was no valuable infrastructures along the coastal area affected by storms.

Mangroves of the delta, like mangroves all over the world are the most productive fishing grounds, providing vast numbers of fish, crabs, shrimps and molluscs. Oysters cling to mangrove roots, crabs and cockles are collected from the mangrove mud, while many other species move with the tides. Fish and shrimp forage among the trees when the tide is high, but congregate in the channels as the water falls. The estimate of the economic value of the fisheries production related to the mangrove ecosystem was made considering the entire mangrove area in the Sofala Bank. It was not possible to assign a value for the mangroves in the delta alone, since fish caught in the delta could have come from surrounding areas, and conversely, fish caught in other areas could have nursed, bread or lived in the Delta. Many fish and shrimp species use mangroves for just a short part of their life-history – adult fish may come into the mangroves to breed, and many larvae or young fish use mangroves as their home in early life. As they mature, such fish and shrimp move out into surrounding waters, to seagrasses, coral reefs and the wider expanses of offshore waters. For that reason, it was considered the fish species related to mangroves caught in Sofala bank, and then integrated to the entire mangrove area.

In the present study the figures of catch and income from fishery products are considered to be underestimated. The catch statistics of artisanal fisheries are highly underestimated as the fishing centers are scattered along the cost, some located in remote places with difficult access for the samplers. In addition, some of the artisanal fishermen operate during the night and call the fishing centers early morning or in the evening when there is no one to record. Nevertheless, the value obtained in the present study of catch income rates per unit of mangrove area of 209 kg ha⁻¹ yr⁻¹ and US\$600 ha⁻¹ yr⁻¹, respectively, fit well with the findings from other authors in studies elsewhere, particularly with the estimate from Fiji by Lal (1990) who obtained on average 331 kg ha⁻¹ yr⁻¹ and US\$100 ha⁻¹ yr⁻¹, and the study by Hatcher *et al.* (1989), who studied the mangrove ecosystem value across many countries in Asia and South America, and obtained US\$561 ha⁻¹ yr⁻¹, for the Philippines and US\$769 ha⁻¹ yr⁻¹, for Brazil. Several studies have indicated that the value of mangrove-related fishery resources ranged from US\$ 120 to 3000 ha⁻¹ yr⁻¹ (Clough 1993; Diop 1993; Lacerda 1993); and fits well within the range of values found through literature search by Hutchison *et al.* (2015) who found the average values of 120.1 kg ha⁻¹ yr⁻¹ and 106.1 US\$ ha⁻¹ yr⁻¹ for inshore mixed species, 45 kg ha⁻¹ yr⁻¹ and 423.4 US\$ ha⁻¹ yr⁻¹ for inshore crab; and 122.3 kg ha⁻¹ yr⁻¹ and 24.3–1,394 US\$ ha⁻¹ yr⁻¹ for offshore prawns.

The mangroves in delta contribute to carbon dioxide sequestration. According to the estimate of Stringer *et al.* (2014) the mangroves in the Zambezi Delta sequester about 463 Mg ha⁻¹ yr⁻¹. These quantities of carbon are tied up both in the living trees of the mangrove forests and in their rich soils. Unlike many other tropical forests, mangroves sequester carbon and store it away in the soils where it can remain for millennia, as the saline, waterlogged conditions prevent the breakdown of organic material by fungi or bacteria. Mangroves are thus often seen as critical for long-term storage and sequestration of carbon – removing carbon dioxide from the atmosphere and storing it in their biomass and soil. Conversely, mangrove destruction can lead to massive releases of carbon dioxide, driven not only by the loss of trees, but by the breakdown of the soil carbon as well (Shapiro *at al.*,

2015). Thus, mangroves in the delta should be maintained. Trading of carbon which would render an estimated US\$6,000 per ha⁻¹ year⁻¹, is hence, suggested, and it would enable promoting alternative livelihood, apart from cutting mangroves, for the local people.

People in the Delta are well aware about the importance of mangroves to their livelihood. The income generated is mainly based in mangrove products and mangrove related products. Although agriculture is widely practiced and there is existence of fertile soils, it is practiced only for subsistence. When enquired about alternative livelihood options most interviewed did not have an option apart from fisheries and mariculture. This positioning can be justified by the fact that fisheries and mangroves are still in the pristine state and so contributing significantly, to the household income, in the delta. However, care should be taken for sustaining exploitation, to avoid overexploitation of the resources and destruction of the habitat, because restoration often takes a long time and could be costly. In that regard, alternative livelihoods apart from cutting the trees, should be identified and promoted for people living in the delta. Suggested options include agriculture, obviously taking advantage of fertile soils; fish processing and conservation, which could greatly increase the fish value, reduce losses post harvesting, and increase household income which, in turn, may result in reduced fishing effort and mariculture. It could include crab fattening and mariculture of fish in cages. Pond aquaculture, which involves digging and destruction of mangroves, is discouraged. There are several mangrove creeks in the delta which are suitable for cage culture, where the tides provide the natural flashing and renewal of water in the ponds.

The present study shows clearly that the mangrove ecosystem render more to the wellbeing of the people when conserved than overexploited. The indirect benefits, those harnessed when mangroves are preserved, worth 98.4%, against 1.6% due to direct benefits of mangrove, those involving cutting of mangroves, of the total value of mangroves in the Zambezi Delta. However, some studies in a degraded mangrove ecosystem and overexploited fish stock situation may mislead the value of conserved mangrove ecosystem. Janssen and Padilla (1999) compared the costs and benefits of mangrove conservation with those generated by various alternative plans of aquaculture (involving cutting of mangroves) and forestry in Philippines and their result indicated that aquaculture generates the greatest value at US\$ 6793 ha⁻¹ yr⁻¹, followed by forestry (US\$ 150 ha⁻¹ yr⁻¹) and fisheries (US\$ 60 ha⁻¹ yr⁻¹). These could have been a, indication of possible heavy deforestation of mangroves for aquaculture and as a result the ecological support of mangrove to fisheries reduced, and hence reduced availability of fish and increased fishing effort. So, to adequately gauge the ecosystem value of an ecosystem, this should be pristine and full functioning, otherwise the result obtained would be incorrect and misleading.

11. Conclusions and recommendations for future studies

11.1. Conclusions

This study provides an estimate of the value of ecosystem services provided by mangroves in Zambezi Delta under a baseline scenario for the period 2013-2015, and cost and exchange rates of 2014. The main mangrove use identified for the Zambezi delta were, for direct use: timber, poles, fuelwood and charcoal, and for indirect use: habitat and nursery which comprises breeding, spawning and nursery habitat for commercial fish species, regulating capacity, which was essentially erosion control and storm buffering, carbon sequestration and cultural service. Thus, the main mangrove ecological services identified for the Zambezi delta were habitat and nursery for fisheries species, erosion control, storm buffering, carbon sequestration and cultural service.

The mangrove ecological service value was estimated by combining data and information provided by government institutions, from literature reviewed and also on stakeholder interviews. The study was limited to valuation of the direct and indirect use values of products and services provided by mangrove ecosystems, which entail the availability of market prices or market prices for substitutes, a method applied in many studies, for it is thought to be relatively easy. The direct use of mangrove was mainly the cutting of mangroves for timber, poles, fuelwood and charcoal production. The indirect use values of mangrove were associated to the spawning, nursery and breeding function of mangrove, where the fisheries constituted the major part of the total value. The value of the carbon sequestration was based in the study conducted by other authors in the area as indicated above. In addition, the value of maritime transport, though it is not related to ecosystem services, was undertaken for completeness as it contributes to boost the socio-economy of the Delta.

The value of the spawning, nursery and breeding function of mangrove depends in a great deal on the ecological linkages between mangrove ecosystem and fish stocks, hence, conscious need to be taken when analyzing the information since, in most cases, valuation of the impacts of a management alternative on catches on fisheries is based on assumptions that often lack scientific solid evidences, and so, are somewhat speculative, due to inadequate knowledge regarding the ecological linkages between mangrove ecosystems and fish populations. Further, the study uses simple arithmetic algorithms linking market price and value catches, ignoring price changes and other economic variables. Given the fact that the ecological relationships involved between mangrove ecosystem and fisheries availability, distribution and species specificity is complex, it requires dedicated ecological research in this area. Future studies may be on the linkage between the river runoff and the availability of fisheries resources, water masses in the estuaries set by tides and river runoff in the ecological zoning and the health of the ecosystems in the delta.

The protective value of mangroves was estimated by the damage avoided, which consisted in estimating the value of the infrastructure at risk. This method depends on the infrastructure available which is an indication of the development status of the sites. This method may imply that mangrove surrounding a developed village worth more than mangrove in a remote poor village.

In the present study the value of direct and sustainable use of mangrove was estimated at US\$1,200 ha⁻¹ yr⁻¹, if exploited for charcoal, on a cycle period of 10 years, and US\$1,040 ha⁻¹ yr⁻¹, if exploited for poles, on a cycle period of 5 years; the ecological services were valued at US\$ 20,000.00 ha⁻¹ yr⁻¹, for coastal protection against erosion; from fisheries nursery obtained the average fish production yield of 209 kg ha⁻¹ yr⁻¹, rendering an average gross income from fish products of US\$600 ha⁻¹ yr⁻¹,

where the income from fish and shrimp were estimated at US\$419.07 ha⁻¹ yr⁻¹ and US\$152.11 ha⁻¹ yr⁻¹, for the entire Sofala Bank, respectively; the carbon sequestration value, based on carbon sequestration rates of 463 Mg ha⁻¹ yr⁻¹ given by Stringer et al. (2014), and considering the average market price of carbon of US\$13 per tonne of CO₂, according to Carbon Planet, was estimated at US\$6,000 per ha⁻¹ year⁻¹. Table 11.1 summarizes the estimated mangrove value of the Zambezi Delta. The overall direct use of mangroves in poles, timber, firewood and charcoal yield was estimated at 1,120 US\$ ha⁻¹ yr⁻¹; the regulating, habitat and nursery and climate regulation functions were estimated at 20,000 US\$ ha⁻¹ yr⁻¹, 600 US\$ ha⁻¹ yr⁻¹ and 6,000 US\$ ha⁻¹ yr⁻¹, respectively. Considering the total area (37,034 ha) of mangrove in the Delta, the direct use of mangrove worth 41,478,080 US\$ yr⁻¹ and the indirect use of mangrove worth 985,104,400 US\$ yr⁻¹ for the entire Zambezi Delta. Thus, the overall mangrove value in the Zambezi delta is estimated at 1,026,582,480 US\$ yr⁻¹. Hence, the indirect benefits, those from ecosystem services, worth 98.4% of the total value of mangroves in the Zambezi Delta, and the direct benefits of mangrove, those involving cutting of mangroves, worth only 1.6% of the overall mangrove value, in addition to causing the loss of the ecosystem value.

Table 11.1. Summary of the estimated mangrove value of the Zambezi Delta.

Provisioning of goods - Direct use of mangroves			Ecological value – Indirect use of mangroves		
Product	Harvesting rate (No of trees ha ⁻¹ yr ⁻¹)	Yield (US\$ ha ⁻¹ yr ⁻¹)	Category	Production rate (kg ha ⁻¹ yr ⁻¹)	Yield (US\$ ha ⁻¹ yr ⁻¹)
Charcoal	156	1,200	Regulating (coastal protection)		20,000
Poles	312	1,040	Habitat and nursery	209	600
			Climate regulation (Carbon sequestration)	463,000	6,000
			Maritime transport (passengers and goods)		264,000

No attempts to value of biodiversity for pharmaceutical neither non-use values for biodiversity were assessed, beside wide recognition of the medical services of mangrove in the Zambezi Delta. The major limitation is associated with attaching value to medicine through traditional healers. It was also not possible to value ecotourism because no ecotourism is currently observed in the area, though, the area has potential for practicing it. Hence, promotion of the ecotourism in de delta based in experiences from other places in the world is encouraged, and could be a potential alternative livelihood.

By comparison analysis of the benefits of mangrove as direct product and as ecosystem service provider the present study found that mangrove worth more and in a sustainable manner to people conserved than cut. This is particularly the case for the coastal protection and fisheries habitat and nursery services, which are off-site services that do not require cutting or access to the mangrove

itself. In the present study the net monthly household income from mangrove direct use, i.e. charcoal production and poles was estimated at US\$53 and US\$105 per house hold per month, respectively, whereas for ecosystem services was estimated at US\$319, US\$413 and US\$192 for fish, shrimp and crab, respectively. Hence, mangrove conservation efforts should therefore include the support of alternative livelihood initiatives for cutting mangrove, in order to better harness the economic benefits of the mangroves. Table 11.2 summarizes the estimated household income from the mangrove products and mangrove ecosystem services in the Zambezi Delta. Overall household income due to direct mangrove use, manly from poles and charcoal, was estimated at 79 US\$ ha⁻¹ Month⁻¹ per house hold, and due to indirect use of mangroves, mainly from fisheries, was estimated at 308 US\$ ha⁻¹ Month⁻¹ per house hold.

Table 11.2. Summary of the estimated household income from the mangrove products and mangrove ecosystem services in the Zambezi Delta.

Provisioning of goods - Direct use of mangroves			Ecological value – Indirect use of mangroves		
Mangrove products	Income (US\$ ha ⁻¹ Month ⁻¹)		Fish products	Income (US\$ ha ⁻¹ Month ⁻¹)	
	Gross income	Net Income		Gross income	Net Income
Charcoal	290	53	Shrimp	449	413
Poles	180	105	Crabs	211	192
			Fish	443	319

11.2. Main recommendations

The present study suggests the support of Income generating agriculture, mariculture, and beekeeping as sustainable alternative livelihood for people in the delta. However, there is a need to conduct studies to determine the technical and economic sustainability of the suggested alternative livelihoods. Further, the study found that mangrove in the delta can be explored sustainably, and in that regard, it is suggested that a household be given a hectare of mangrove to explore and sustainable harvesting levels be assigned. Income generating agriculture is proposed to be implemented in Luabo, Inhacatiua and Malingapasse. In Inhacatiua there is a tide irrigation system, the Sombo Irrigation that could be supported. Mariculture could be developed in most of the coastal villages, the present study, however, suggests to be implemented in Bairro Hospital, Bairro Amarelo and Bairro Aeroporto in the Chinde Sede, and Matilde and Pambane. The implementation of the activity should be monitored by the Natural Resources Management Committees. For mangrove sustainable exploitation the study considers a mature tree of 7.5 m height and 2.5m perimeter, attain in a cycle period of 10 years, and in an average mangrove density of 1,800 trees per hectare, for fuelwood and charcoal production. The sustainable exploitation of mangrove is suggested to be implemented in Bairro Hospital and Bairro Amarelo, in Chinde Sede and in Pambane, and assigned a household for exploiting one hectare of mangrove, thus, involving about 281,074 households, supervised by Community Mangrove Management Committees.

Furthermore, mangroves should be replanted to replace those that are being cut or that dyed. The Natural Resources Committees or Mangrove Management Committees be established, trained and empowered to effectively oversee the implementation of the mangrove management plan. Further collaborative and multidisciplinary studies combining mangrove ecology and economics to model the provision and value of ecosystem services from mangroves are required. There is also a need for that combines mangrove ecology and economics to jointly model the provision and value of ecosystem services from mangroves.

During the course of the present study became evident the potentials of the economic valuation methods for evaluating mangrove ecosystem services. However, the practical application of these methods was a challenge due to lack of data. Literally, there are well sound methods available for the valuation of the full range of products and services provided by mangrove ecosystems; but the lack of data and quantitative knowledge regarding some key ecological relationships present major constraints. Hence, effort for collecting quantitative data for an adequate valuation of the economic value of mangrove ecosystem services should made in the future.

The present study reiterated that freshwater discharge as well as the marine water inflow into the delta is of great importance for the health of the ecosystems and communities. Mangroves require balanced freshwater and marine water to set and adequate salinity range. This depends on the by the frequency and duration of the flooding of the delta largely by the upstream water through the Zambezi river, on one hand, and set by the tides from the sea, on the other hand. Hence, there is a need to establish and maintain an ecological river runoff through the Cahora Bassa dam, and perhaps including Kariba dam.

The stakeholder analysis was based on a qualitative analysis to capture the awareness, perceptions, interests and concerns of the different stakeholders regarding the importance of the mangrove ecosystem in their livelihood, and their willingness to restore and conserve the mangrove

ecosystems. Most of the people interviewed were knowledgeable of the value of mangroves and willing to contribute to their restoration and conservation.

In summary, the present study concludes that the mangroves in the Zambezi delta contributes significantly to the wellbeing of the people by providing a number of direct products such as timber, building poles and fuelwood, and indirect use values such as spawning, nursery and breeding grounds for fish, and protection against erosion. However, further detailed studies to infer a more quantitative analysis and predict trends more accurately are required. In addition studies for determining the technical and economic viability of the suggested alternative livelihood activities to mangrove cutting should be undertaken. The following activities are recommended:

- Establishment of a mangrove management system and sustainable exploitation of mangrove tree products such that sustainable harvesting is set at 13 trees per hectare per month is allowed for fuelwood and charcoal production in Bairro Amarelo in Chinde Sede and Pambane. Such exploitation be attributed to a household per hectare and controlled by the Community Mangrove Management Committees;
- Promotion of incoming generating agriculture in Inhacatiua, Luabo and Malingapasse as an alternative livelihood activity to mangrove cutting;
- Support of fish processing and trade, to reduce post-harvest losses, add value to fish product and increase income in Bairro Hospital, Bairro Amarelo and Bairro Aeroporto, in Chinde Sede and in Matilde and Pambane;
- Promotion of crab fattening to increase income and reduce pressure on wild stocks and ecosystems in Bairro Hospital, Bairro Amarelo and Bairro Aeroporto, in Chinde Sede and in Matilde and Pambane;
- Promotion of beekeeping in mangrove forest in Bairro Faina and Bairro Arrozal, in Chinde Sede, in Matilde, Pambane, Inhagurue and Malingapasse;
- Promotion of the use of bricks, taking advantage of abundant clay, for building houses as an alternative to mangrove timber and poles in all the delta;
- Management of the Cahora Bassa dam as to mimic the natural seasonal cycle as maximum as possible.

12. References

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Appendix - I - Description of captured fish and crustacean species related to mangrove ecosystems.

The captured species related to mangroves as described in FishBase by Rainer, Daniel Pauly (2014) and in the *Encyclopedia of Fishes by Gareth (1998)*, are listed below:

- Penaeidae shrimps are found in offshore waters on sandy bottoms at depths of 20–40 meters. The larvae move towards the coast, enter estuaries and mangrove swamps which serve as nursery ground. The shrimps spend their juvenile, adolescent and sub-adult stages in estuarine waters and then gradually move toward deeper water as they grow and eventually returning to offshore water when they attain sexual maturity;
- Sergestidae, with major genus *Acetes*, a small krill-like prawns. Live in estuaries and coastal waters of tropical and subtropical regions. Spawning of pelagic shrimp usually occurs in open water of less than 50 m depth, often much shallower, and the larvae and juvenile development occurs in sheltered estuaries and mangrove swamps (Arshad *et al.*, 2007);
- Mangrove crab, *Scylla serrata*, often called mud crab or mangrove crab, is an economically important species of crab found in the estuaries and mangroves in tropical regions;
- Eugralidae comprises the anchovy. They are schooling fishes, mostly of shallow coastal waters and estuaries in tropical and temperate regions. Some species enter or live in freshwater;
- Clupeidae is a family of ray-finned fishes, comprising, for instance, the herrings, shads, sardines, hilsa, and menhadens. Common in Mozambique are sardines and hilsa. Clupeids are typically marine, coastal, and schooling fishes. Some species tolerate low salinities, sometimes entering fresh water to feed, and other species undergoing regular migrations up rivers to spawn, and some species may live permanently in fresh water;
- Sciaenidae are found worldwide, in both fresh and salt water, and are typically benthic carnivores, feeding on invertebrates and smaller fish. They are small to medium-sized, bottom-dwelling fishes living primarily in estuaries, bays, and muddy river banks. Most of these fish types avoid clear waters, such as coral reefs and oceanic islands, with the exception of reef croaker;
- Trichiuridae, of the Perciformes is found in seas and in brackish water in estuaries throughout the world;
- Carangidae is a family of fish which includes the jacks, pompanos, jack mackerels, runners, and scads. They are marine fishes but also found in brackish water;
- Ariidae or ariid catfish are a family of catfish that mainly live in marine waters with many freshwater and brackish water species. They are found worldwide in tropical to warm temperate zones;
- Haemulidae is a family of fishes in the order Perciformes known commonly as grunts. They are shallow, nearshore water fishes, found in tropical fresh, brackish, and salt waters around the world. They are bottom-feeding predators, and named for their ability to produce sound by grinding their teeth;
- Scombridae family of the mackerels, tunas, and bonitos, include many of the most important and familiar food fishes. They are generally predators of the open ocean, and are found worldwide in tropical and temperate waters; although some groups occur in brackish water. They migrate to shallow and brackish water for feeding (Johnson and Gill, 1998);

- Mungilidae, the mullets or grey mullets are a family of large, marine fishes inhabiting estuaries, coastal waters, brackish waters, and even freshwater. Adult mullet live in shallow coastal areas, often in schools, over sand, mud or seagrass beds down to depths of about 10 m. They may enter rivers but do not necessarily require freshwater. They breed off shore in coastal waters. The larvae drift in the sea and enter in shallow inshore areas where they grow to juvenile and adult stage;
- Sphyraenidae, the barracuda is a ray-finned fish. It is a saltwater fish of the genus *Sphyraena*, and is found in tropical and subtropical oceans worldwide. Most of them inhabit shallow coastal waters such as bays and estuaries;
- Leiognathidae, the ponyfishes, also known as slipmouths or slimys/slimies, are a small family, Leiognathidae, of fishes in the order Perciformes. They inhabit marine and brackish waters in the Indian and West Pacific Oceans. They live near the bottom in shallow coastal waters, with several species entering brackish waters, especially river estuaries, a few ranging up into fresh water. They occur at depths as shallow as 0.5 m and down to around 160 m;
- Polynemidae, Threadfins, are silvery grey perciform marine fish of the family Polynemidae. Found in tropical to subtropical waters throughout the world. Threadfins frequent open, shallow water in areas with muddy, sandy, or silty bottoms. They may enter estuaries or rivers;
- Sepiidae are cuttlefish, belong to cephalopoda. They are marine animals of the order Sepiida, which contains all cuttlefish. They inhabit tropical/temperate ocean waters. They are mostly shallow-water animals;
- *Psetodidae*, Inhabit shallow brackish water in coastal, estuaries. They enter rivers and mangrove swamps;
- *Platycephalidae* are a family of marine fish, most commonly referred to as flat heads. They are found in coastal waters, on mud or sand bottoms;
- *Therapon*, are marine, freshwater and brackish species. The adults inhabit coastal waters, often found in brackish waters;
- *Drepanidae*, known commonly as the sickle fishes, occur in various inshore habitats: sand or mud bottoms, reefs, estuaries and harbors;
- *Cynoglossidae*. tonguefishes, are flatfishes in the family Cynoglossidae. They are commonly found in shallow waters on a muddy or sandy bottom, including estuaries and a few species are restricted to fresh water;
- *Batoidea*, are rays, type of flattened fish and are closely related to sharks. Rays evolved from sharks. Most species live on the sea floor, in a variety of geographical regions, mainly in coastal waters and even in some estuaries;
- Sharks inhabit open ocean and the shallow coastal waters. The bull sharks, known as Zambezi sharks live in both salt and fresh water successfully. They prefer to live in shallow waters such as river mouths, bays, and estuaries of tropical to subtropical coastal waters.

Appendix II – Interview Questionnaires

A) Mapa de produtores e revendedores

Local _____ Data ____/____/2016

Nome do inquirido: _____

Género: Masculino _____ Feminino _____ Idade _____

No de agregado familiar _____ Quantos contribuem para renda _____

Fontes de renda _____

Actividade do inquerido:

Pescador _____ Colector _____ Processador _____ Transportador _____

Produtor estacas _____ Produtor de lenha _____ Produtor de carvão _____

Produtor de mel _____ Vendedor de peixe _____ Vendedor de estacas _____

Vendedor de lenha _____ Vendedor de carvão _____ Vendedor de mel _____

Outra especifique _____

Valor directo de produtos de mangal

Produto	Qtd/mês	Preço unitário	Preço total/mês
Estaca			
Lenha			
Carvão			
Peixe			
Camarão			
Caranguejo			
Thodwe			
Ameijoa			
Mel			
Ostras			
Total			

Espécies de peixe

Espécies	Qtd/mês	Preço unitário	Preço total/mês

B) Mapa resumo de produtores e revendedores

População total do distrito _____

Masculino _____ Feminino _____

População por faixa Etária: < 18 _____ [18, 35] _____ >35 _____

	Número de pessoas	Quantidade anual produzida	Receita total anual
Produto			
Estaca			
Lenha			
Carvão			
Peixe			
Camarão			
Caranguejo			
Thodwe			
Ameijoa			
Mel			
Outros			
Total			

Valor do consumo de produtos de mangal

Produto	Qtd/mês	Custo unitário	Custo total/mês
Estaca			
Lenha			
Carvão			
Peixe			
Camarão			
Caranguejo			
Thodwe			
Ameijoa			
Mel			
Outros			
Total			

C) Mapa resumo de consumidores

População total do distrito _____

Masculino _____ Feminino _____

População por faixa Etária: < 18 _____ [18, 35] _____ >35 _____

	Número de pessoas	Quantidade anual consumida	Gasto total anual
Produto			
Estaca			
Lenha			
Carvão			
Peixe			
Camarão			
Caranguejo			
Thodwe			
Ameijoia			
Mel			
Outros			
Total			

D) Mapa de actividades de subsistência

Local _____

Data ____ / ____ / 2016

Nome do inquirido _____

Género: Masculino _____ Feminino _____ Idade _____

No de agregado familiar _____ Quantos contribuem para renda _____

Fontes de renda

Pesca () Agricultura () Aquacultura ()

Produtor de sal () Turismo () Comércio ()

Pequenas indústrias () Função pública () Produtor de estacas ()

Produtor de lenha () Produtor de carvão () Pedreiro ()

Carpinteiro () Artesão () Médico tradicional ()

Outra especifique _____

E) Mapa de actividades alternativas de subsistência

(Para os que vivem de corte de mangal para estacas, carvão e lenha)

Local _____ Data ____ / ____ / 2016

Nome do inquirido _____

Género: Masculino _____ Feminino _____ Idade _____

Nº de agregado familiar _____ Quantos contribuem para renda _____

Indique a fonte alternativa de renda de preferência (agricultura, aquacultura, mel...) Existe uma outra actividade que poderia realizar no lugar do corte do mangal?

Sim () Não ()

Se sim, mencione as fontes alternativas

F) Mapa de actividades alternativas de subsistência

(Para os que vivem de revenda de estacas, carvão e lenha de mangal)

Local _____ Data ____ / ____ / 2016

Nome do inquirido _____

Género: Masculino _____ Feminino _____ Idade _____

No de agregado familiar _____ Quantos contribuem para renda _____

Indique a fonte alternativa de renda de preferência (comércio, pequenas indústrias)

G) Mapa de construções com material de mangal

Local _____ Data ____ / ____ / 2016

Nome do inquirido _____

Género: Masculino _____ Feminino _____ Idade _____

No de agregado familiar _____

Tipo de habitação

Paredes	Mangal	Caniço	Alvenaria	Chapas? Tábuas?
Outros				
Cobertura capim				
Cobertura chapas				
Tamanho				
Duração				
Custo				

H) Mapa resumo de construções com material de mangal

População total do distrito _____

Masculino _____ Feminino _____

População por faixa Etária: < 18 _____ [18, 35] _____ >35 _____

Número total de casas _____

Tipo de habitação

Paredes	Quantidade	Custo
Outros		
Mangal/Cobertura capim		
Mangal/ Cobertura chapas		
Alvenaria		
Outro material		
Total		

I) Mapa de material de construção alternativos

(Para os que vivem de corte de mangal para estacas, lenha e carvão)

Local _____ Data ____ / ____ / 2016

Nome do inquirido _____

Género: Masculino _____ Feminino _____ Idade _____

Nº de agregado familiar _____ Quantos contribuem para a renda _____

Tem conhecimento da existência, aqui no Chinde, de outro material que pode ser usado para construção de casas? Sim () Não ()

Se sim, indique a fonte alternativa de material de construção (caniço, bloco queimado, blocos normais...)

J) Mapa de material de construção alternativos

(Para os que possuem casas construídas de material extraído do mangal)

Local _____ Data ____ / ____ / 2016

Nome do inquirido _____

Género: Masculino _____ Feminino _____ Idade _____

Nº de agregado familiar _____ Quantos contribuem para renda _____

Tem conhecimento da existência, aqui no Chinde, de outro material que pode usar para construção de casas? Sim () Não ()

Se sim, indique o tipo de material alternativo de preferência (caniço, bloco queimado, blocos normais...)

K) Mapa sobre a opinião da comunidade sobre a importância dos serviços ecossistêmicos

Local _____ Data ____ / ____ / 2016

Nome do inquirido _____

Género: Masculino _____ Feminino _____ Idade _____

Nº de agregado familiar _____ Quantos contribuem para renda _____

Fornecimento de alimentos

Você ou alguém que você conhece obtém alimentos do mangal, seja para consumo próprio ou para venda?

Considera o serviço presente () Considera o serviço ausente ()

Como você avalia este serviço para os residentes de Chinde?

Muito importante () Importante () Pouco importante () Não é importante ()

Mangal e disponibilidade de pescado

Qual ou quais dos seguintes recursos acha que não existiriam se não houvesse mangal?

Peixe () Caranguejo () Camarão () Todwe ()

Como você avalia este serviço para os residentes de Chinde?

Muito importante () Importante () Pouco importante () Não é importante ()

Fornecimento de mel

Você ou alguém que você conhece obtém mel do mangal, seja para consumo próprio ou para venda?

Considera o serviço presente () Considera o serviço ausente ()

Como você avalia este serviço para os residentes de Chinde?

Muito importante () Importante () Pouco importante () Não é importante ()

Fornecimento de medicamento

Você ou alguém que você conhece obtém medicamento do mangal, seja para consumo próprio ou para venda?

Considera o serviço presente () Considera o serviço ausente ()

Como você avalia este serviço para os residentes de Chinde?

Muito importante () Importante () Pouco importante () Não é importante ()

Considera o serviço presente () Considera o serviço ausente ()

Fornecimento de material de construção

Você ou alguém que você conhece obtém material de construção do mangal, seja para uso próprio ou para venda?

Como você avalia este serviço para os residentes de Chinde?

Muito importante () Importante () Pouco importante () Não é importante ()

Fornecimento de combustível (lenha e carvão)

Você ou alguém que você conhece obtém lenha e carvão do mangal, seja para uso próprio ou para venda?

Considera o serviço presente () Considera o serviço ausente ()

Como você avalia este serviço para os residentes de Chinde?

Muito importante () Importante () Pouco importante () Não é importante ()

Patrimônio e identidade cultural

O mangal tem alguma importância cultural para você?

Considera o serviço presente () Considera o serviço ausente ()

Como você avalia este serviço para os residentes de Chinde?

Muito importante () Importante () Pouco importante () Não é importante ()

Lazer e Recreação

Você ou alguém que você conhece utiliza o mangal para recreação?

Considera o serviço presente () Considera o serviço ausente ()

Como você avalia este serviço para os residentes de Chinde?

Muito importante () Importante () Pouco importante () Não é importante ()

Protecção costeira

Você considera que o mangal evita a erosão da costa do Chinde?

Considera o serviço presente () Considera o serviço ausente ()

Como você avalia este serviço para o distrito de Chinde?

Muito importante () Importante () Pouco importante () Não é importante ()

Appendix III – List of Stakeholders - Stakeholders influence, impact and interest mapping for conservation and sustainable use of mangroves in the Zambezi Delta.

Stakeholder name	Impact (how much the project does impact them?)	Influence (how much influence do they have over the project?)	What is important to the stakeholder?	How could the stakeholder contribute to the project?	How could the stakeholder block project?	Strategy to engage the stakeholder
Beneficiaries						
Local community	High	Moderate	Main beneficiaries -Resource use -Ecosystem restoration and conservation -Livelihood activities	Human resources	Losing interest and not participating if the project fails to meet their expectations	Meetings and feedback information and involvement in the project planning and implementation
CBO Artisanal Fisheries Association, Natural Resources Management Committees, Fisheries Management Committees	High	High	Implement activities of -Resource management -Ecosystem restoration and conservation -Livelihood activities	Human resources	Campaigns in the communities and lobbies in the government against the project and mobilize the stockholders not to adhere the project if it fails to meet the local communities' interest	Meetings and feedback information and involvement in the project planning and implementation
Executing stakeholders (management)						
UEM – Marine Research and Technology	Moderate	High	Implement activities of -Resource management	-Human resources, knowledge, technology and equipment	Lobbies in the government and in the sponsors not to support the project if the project	Engaging them in the project planning and implementation

Canter (UEM- CePTMar)			-Ecosystem restoration and conservation -Livelihood activities -Technology innovation and testing -knowledge development and application	-Conduct scientific research and technology innovation and adaptation -Improve knowledge about the potential and value of the mangrove ecosystem -Identify and define appropriate conservation measures-Conduct studies on the technical and ecological viability of the development activities -Short term training of community and extension workers -Dissemination of scientific information	fails to meet the local communities' interests	
RADEZA and ORAM	Moderate	High	Implement activities of -Resource management -Ecosystem restoration and conservation -Livelihood activities	- Human resources, knowledge, technology and equipment	Campaigns in the communities and lobbies in the government against the project and mobilize the stockholders not to adhere the project if it fails to meet the local communities' interests	Engaging them in the project planning and implementation
UEM - School of Marine	Moderate	High	Implement activities of	-Human resources, knowledge,	Lobbies in the government and in the	Engaging them in the project planning and

and Coastal Sciences			<ul style="list-style-type: none"> -Resource management -Ecosystem restoration and conservation -Livelihood activities -Technology innovation and testing -knowledge development and application 	<ul style="list-style-type: none"> technology and equipment -Conduct scientific research and technology innovation and adaptation -Improve knowledge about the potential and value of the mangrove ecosystem -Identify and define appropriate conservation measures -Short term training of community and extension workers -Dissemination of scientific information 	sponsors not to support the project if the project fails to meet the local communities' interests	implementation
Executing stakeholders (participants)						
WWF	Low	High	<ul style="list-style-type: none"> -Ecosystem conservation -Mangrove rehabilitation -Sustainable use of natural resources -Community development 	Co-funding and implement activities	Lobbies in the government against the project and mobilize the sponsors not to support the project if it fails to meet the ecosystem conservation principles	<ul style="list-style-type: none"> -Involve them on the project steering committee -Inform them about the implementation of the project on a regular basis
Government at District level	High	High	<ul style="list-style-type: none"> -Decision making -Fulfilment of their mandates -Enforcement of environmental 	<ul style="list-style-type: none"> -Provide extension worker services -Mobilizing the local communities to adhere to the project 	Order the interruption of the project if it fails to meet the local community and government interests	Engaging them in the project planning and implementation, and assure the mainstreaming the project activities to the

			<ul style="list-style-type: none"> regulations -Provide enabling environment for the implementation for the activities -Mainstreaming of the environmental issues and development initiative in the regulations and plans 	<ul style="list-style-type: none"> -Resources for the project implementation (transports, office facilities) 		government and local needs
Government at Provincial level	High	High	<ul style="list-style-type: none"> -Decision making -Fulfilment of their mandates -Enforcement of environmental regulations -Co-Funding activities -Provide enabling environment for the implementation for the activities -Mainstreaming of the environmental issues and development initiative in the regulations and plans 	<ul style="list-style-type: none"> -Liaise with the National Government -Mobilizing the Provincial stakeholders (academia, private sector (including banks) and NGO's) to support the project -Resources for the project implementation (transports, office facilities) 	Order the interruption of the project if it fails to meet the local community and government interests	Engaging them in the project planning and implementation, and assure the mainstreaming the project activities to the government and local needs
Government at national	Moderate	High	<ul style="list-style-type: none"> -Decision making -Fulfilment of their 	<ul style="list-style-type: none"> -Liaise with the international partners 	Order the interruption of the project if it fails to	Engaging them in the project planning and

level			mandates -Enforcement of environmental regulations -Co-Funding activities -Provide enabling environment for the implementation for the activities -Mainstreaming of the environmental issues and development initiative in the regulations and plans	(sponsors, potential co-sponsors) -Mobilizing the national stakeholders (academia, private sector (including banks) and NGO's) to support the project -Resources for the project implementation (co-funding)	meet the local community and government interests	implementation, and assure the mainstreaming the project activities to the government and local needs
Oversight (potential co-sponsors)						
DANIDA	Low	High	-Sustainable development -Community development - Climate change -Capacity building	Co-fund activities	Lobbies in the government against the project and mobilize the sponsors not to support the project if it fails to meet the sustainable development goals	Inform them about the implementation of the project on a regular basis
Banks: BCI, Socremo, Letsego	Moderate	High	-Business -Income generating activities -Investment	-Co-funding income generating activities -Management of funds -Promote microcredit financing scheme for the entrepreneurs	Lobbies in the government against the project not to support the project if the activities are not economically viable	Inform them about the implementation of the project
Oversight (potential advisors)						

Private sector: Companhia de Sena SARL, Marromeu and Luabo Sugar Plant	Moderate	Moderate	Products from the development activities (fish, oysters, mussels, crabs)	Provide market facilities	Lobbies in the government against the project and mobilize the sponsors not to support the project if it conflicts with the private sector development (e.g. tourism)	Inform them about the implementation of the project, on a regular basis, and create enabling environment to accommodate them suggestions in the implementation of the project activities
Polytechnic University (Politecnica) Pedagogic University (UP)	Moderate	Moderate	-Knowledge on ecosystem and natural resources distribution and availability -Knowledge and technology for sustainable development activities -Internship for the students -Project and dissertation for students	2.1.1 -Conduct scientific research 2.1.2 -Conduct studies on the economic viability of the development activities	Lobbies in the government against the project if it fails to contribute to community income generation expectations	Inform them about the implementation of the project, and create enabling environment to involve their students and lectures in the activities of the project
Media	Low	High	Look for good story to report	Print and broadcast interesting and innovative stories related to development communities	Printing and broadcasting failures and stories against the project	Regular press meetings



Source: Mangrove Action Project website

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