Ecosystem Services Valuation of mangrove forests in Zambezi delta under the Blue Forest Initiative and Sustainable Financing of Protected Areas of Mozambique

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Executive summary

The Zambezi Delta is an alluvial plan triangular shaped, about 120 km long towards the coast and 200 km along the coast, covering an area of about 12,000 km^2. It has several branches and mangrove creeks. The ecosystems comprise freshwaters and wetlands, marine and coastal area, savannah encompassing grassland, woodlands, mangroves and freshwater swamp vegetation, coastal dunes.

The Delta hosts an important rich and diversity ecosystems of endemic fauna and flora. The Marromeu wetland is a Ramsar site. 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. In particular, the extensive mangrove creeks and estuaries are a nursery and breeding ground to important fisheries.

In the Delta live 188,206 people from whom 50.5% are women, distributed over two districts and provinces: the Districts of Marromeu, in Sofala Province and the District of Chinde, in Zambézia Province. These people 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. Natural threats include storms and anthropogenic threats include artificial river runoffs from Zambezi and overexploitation of mangrove forest. Artificial runoffs poses excess freshwater during the dry season and flooding and siltation of mangrove roots during wet season, and mangroves are overexploited for building material, firewood and charcoal production.

While the indirect benefits due to ecosystem services of mangroves have enormous potential to contribute to the livelihood of the local communities and to the economy of the country, their real economic value in terms of the monetary figure is not well known. The ignorance about ecological value of mangrove may hamper the efforts for their sustainable use and conservation and we have witnessed, instead, their devastation, conversion into aquaculture and salt ponds and often used as waste damping sites.

The study

With the aim of create awareness on the importance and value of the mangrove ecosystems, and therefore, fostering the conservation and adoption of sustainable management measure of these important ecosystems WWF-MCO with the support of Blue Forest commissioned the preset study which fit under the Blue Forest Initiative and Sustainable Financing of Protected Areas of Mozambique, to the UNESCO Chair of the Marine Sciences and Oceanography of the Eduardo Mondlane University; envisaging to improve our understanding of the economic value of the ecosystem services provided by mangroves. In order to achieve this objective a multidisciplinary studies encompassing the following subject areas: oceanography, mangrove ecology, forestry engineering, GIS and remote sensing and socio-economy was set, aiming specifically at:

- Identifying relevant ecosystem services provided by mangrove forests of Zambezi;
- Understanding the overall economic efficiency of the various ecosystems services (direct and indirect) provided by mangroves in Zambezi delta;
- Characterizing biophysical and economic environment to determine the supply of services;
- Characterizing socioeconomic environment to determine beneficiaries and demand for services and identify critical delivery areas;
- Identifying threats and future scenarios and associated states and assess impacts of fuelwood extraction and illegal logging and the extraction of other materials (e.g. food; extraction of

honeybee) on mangrove forests ecosystem services; and unsustainable use of fisheries resources;

- Identifying sustainable livelihood apart from direct mangrove products as a means to reduce pressure on mangrove forests, and hence, promote their conservation and improve the economic income of the local community.

Methodology

In order to estimate the economic value associated with mangrove and the economic benefits that could be obtained from sustainably use and management of this ecosystem, 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 was applied. The overall questions addressed were as follows:

- What are the direct values of different mangrove ecosystem products (e.g. fish, crustaceans, molluscs and products)?
- What are the indirect values of different mangrove ecosystem services (e.g. coastal protection and fish habitat)?
- How, overall, 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?

In order to answer those questions a survey based evaluation method, focusing on resources of value to livelihoods, assessing non-market as well as market values, and involving communities was applied. 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.

Data were obtained through semi-structured interviews targeting households, markets and artisanal fisheries centres and through government official statistics. 573 households distributed in 12 villages, in the district of Chinde and surroundings were interviewed. Data on fish catches were obtained from the IIP reports of 2014. In addition the information on maritime transports, major routes, goods transported and value and on carbon sequestration and trading were collected. The data and information was recorded and processed in Excel. GIS was applied to map the surveyed locations.

The economic benefit of ecosystem, given in value per hectare of mangrove per year, was evaluated using market price from the primary producers and considering the total mangrove area as estimated in 2014. The study focused in the following direct benefits of mangrove ecosystems: timber, fuelwood and fisheries production, and indirect benefits due to protective service of mangrove estimated through damage avoided. The result on household benefit was given in value per household per year. 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.

Hydrology and Oceanography

The hydrology is determined by the Zambezi river, the largest in East and Southern Africa, with the annual discharge of the order of 140 km^3. The river is regulated by two main hydroelectric dams: the Kariba dam, with capacity of generating 1,626 megawatts, in Zimbabwe/Zambia and the Cabora Bassa dam, with capacity of generating 2,075 megawatts, in Mozambique. The management of the dam for hydroelectric production have changed considerably the natural hydrological cycle, providing high flows during the dry season and low flows during the wet season. The pick were reduced by 50%, living the runoff almost constant throughout the year.

The oceanography is determined by large tides, of the order of 5 m range during the neap; NE-SW tidal currents of the magnitude of 20-230 cm s^{-1}, and north going residual coastal current; and SE wind waves of 1-2 m significant wave height. Storms occur with a frequency of 1 in every 2.5-5 years. The watermasses at the river mouth are dominated by freshwater. The salinity drops down to 5 at less than 5 km upstream. The sediment flux at the mouth is of magnitude 22.0-29.9 kg s^{-1}, with a net outflow of the magnitude of 7.9kg s^{-1}.

Ecology

The region is characterized by flatland with river braches and several mangrove creeks. The characteristic topographic features are coastal parallel dunes, dune depressions, tide flood plains, flooded alluvial deltaic rich in clay soils and beaches riches in heavy metals. The vegetation is predominantly flooded savannah and mangroves. The present study targeted the mangrove and associated fisheries ecosystems. The main mangrove tree species in the Delta are as follows: *Avicennia marina*, *Bruguiera gymnorhiza*, *Ceriops tagal*, *Heritiera littoralis*, *Lumnitzera racemosa*, *Rhizophora mucronata*, *Sonneratia alba* and *Xylocarpus granatum*.

The terrestrial fauna includes large mammals, migratory birds and crocodiles. The fisheries are dominated by freshwater, brackishwater and marine species, which include catfish and tilapia's for freshwaters species and marine species included high valued Penaeidae shrimp dominated by species *Penaeus indicus* and *Metapenaeus monoceros*, mud crabs of specie *Scylla serrata*, small pelagic with main species *Pellona ditchela* and *Thryssa vitrirostris.*

State of mangrove conservation and mangrove use

The estimated area of mangrove in the delta is about 37,034 ha, with an increase rate of 196 ha yr^{-1}. The mangrove density varied on average from 1550 and 26,900 trees per hectare in a old (30 years old) and new (4-5 years old) stand forests, respectively. In an old stand forest over 97% of the trees had heights between 10 and 30 cm and about 55% had diameters between 10-20 cm and 30% were trees with diameter 30-50 cm. In a new stand about 95 % of the trees had heights less than 3 m, and about 58% had diameters 8-20 cm, about 40% had diameters 20-30 cm. The rate of forest regeneration varied between 6.5% and 99% for old and new stand forest.

The population cut mangroves for timber for building houses and furniture production, firewood and charcoal production. They are selective on cutting mangroves; they go for large trees or branches, and they cut the trees at 0.5-1 m above the ground, allowing for easy regeneration. In addition, they explore the fisheries resources, which are indirect products of mangroves.

Livelihood activities in the Delta

The major livelihood activities in the Delta are as agriculture, fishing and mangrove forest product harvesting for timber, building material, firewood and charcoal production. Agriculture is mainly practiced for subsistence while fisheries and mangrove forest product harvesting are used for income generating. Women are involved in all the activities but fishing is mainly practiced by men and women only involved in fish product trade.

Economic value of mangrove direct products

Mangroves in the Delta provide timber, poles and firewood, from which charcoal is produced. The mangrove economic value for sustainable forest exploitation was estimated at US$1,200 ha^{-1} yr^{-1}, if exploited for charcoal, on cycle period of 10 years. Considering the population of the delta, estimated at 188,206, the charcoal production from mangrove would render about US$236 ha^{-1} yr^{-1}, equivalent to the average GDP per capita in Mozambique. If explored sustainably as poles, the cycle period would be 5 years, and would render US$1,040 ha^{-1} yr^{-1}, equivalent to US$204.64 per capita per year, slightly less than if explored as charcoal. It is believed that if explored as timber would render more, however, the cycle period would be 20-30 years.

Economic value of protective function of mangrove

The village of Chinde is eroding at the rate of 30 m^{-1} yr^{-1}, in a section of about 1,500km along the beach. The threatened infrastructures worth US$1,498,312.79. Considering that a strip of mangrove of about 400-500 m width and 1,500 m long would be sufficient to protect the village against erosion; the protective value of mangrove was estimated at US$ 20,000.00 ha^{-1} yr^{-1}.

Economic value of the ecological function of mangrove

Mangrove provide breeding, spawning and nursery habitat for 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, nursing and feeding. The result from present study indicated that 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}, and the overall gross income from fish products was US$600 ha^{-1} yr^{-1}, with the highest contribution from fish with US$419.07 ha^{-1} yr^{-1}, followed by shrimp with US$152.11 ha^{-1} yr^{-1}, for the entire Sofala Bank.

Carbon sequestration

Mangrove forests have the ability to sequester carbon from atmosphere and store in soil and in dead roots, contributing to reduce green house gases in the atmosphere and mitigating the effect of global climate change. The estimated rate of carbon sequestration by mangroves in the Zambezi Delta was 463 Mg ha^{-1} yr^{-1}. Considering the average market price of carbon of US$13 per tonne of CO_2, according to Carbon Planet, the carbon sequestered by the mangroves in the Zambezi Delta would worth US$6,000 per ha^{-1} $year^{-1}$.

Overall mangrove value

Table (i). Summary of the estimated mangrove value of the Zambezi Delta.

Provisioning of goods - Direct use of mangroves			Ecological value – indirect use of mangroves		
	Harvesting rate (No of trees ha^{-1} yr^{-1})	Yield (US$ ha^{-1} yr^{-1})		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

Maritime transport

Mangrove creeks and estuaries provide vein of communication which holds the maritime and inland waterway transports convenient and affordable. 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 US$64,000 per year on the transport of passengers and about US$200,000 per year on the transport of goods.

Perception of the households on the value of mangroves

About 573 household, from which about 22% were women, distributed in 12 villages, were interviewed. The primary livelihood activities are mangrove harvesting for timber, firewood and charcoal production; fisheries and agriculture and the combinations of two or three of primary activities and others. The category of others includes 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. The charcoal and timber production are mostly carried out by younger people, of age 18-25, extending up to age 45; fisheries, agriculture and trade are activities practiced by people of all active age, 18-60, however, the majority fishermen and trade groups are in mid age, 26-40, and majority in agriculture group is in advanced adult age, 46-50. Most of women are involved in agriculture (30%) and combination of agriculture with either timber (8%) and charcoal (10%) production and fisheries (12%). The households asked what they would prefer as the livelihood alternative to mangrove harvesting most said would prefer agriculture (45%), other fisheries (13%) and trade (15%); few said would practice honey production (8%) and a significant proportion said to have no other alternative (10%).

The household interviewed were well aware about the importance of mangrove in ecology and in sustaining livelihood. Nearly 95% of the interviewed said to be aware that mangrove provides timber, building material, firewood and charcoal considered the service very important in their livelihood. Almost all the interviewed said to know that mangrove provides food through fisheries and that it contributes significantly to their livelihood. In overall about 60% of the interviewed household were aware of the possibility of practicing beekeeping in mangrove forests, and a quite significant proportion (40%) said the service was absent and ranked it less important in their livelihood. About 90% of the interviewed said mangrove provides protection against erosion and buffer to storms and ranked the service as very important. Large proportion of the households interviewed (70%) was not aware of the fact that mangrove sites are used traditional rituals. About 70% of the interviewed said to be aware that in mangrove forest they can get medicine. In the view of the importance of mangrove in their livelihood, nearly 90% of the interviewed said to be willing to contribute in labor for mangrove reforestation.

Household income

Based in the interview result the gross income from charcoal render about US$290 per household per month, with net income of US$53 per household per month; poles for building render about US$180 per household per month, with a net income of US$105 per household per month. Shrimp, crabs and fish render a gross income of US$449, US$211 and US$443 per household per month, respectively; with a net income of US$413, US$192 and US$319 for Shrimp, crab and fish products, respectively. Table (ii), below summarises the estimated household income from the mangrove products and mangrove ecosystem services in the Zambezi Delta.

Table (ii). 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		
	Gross income (US$ ha^{-1} $Month^{-1}$)	Net Income (US$ ha^{-1} $Month^{-1}$)		Gross income (US$ ha^{-1} $Month^{-1}$)	Net Income (US$ ha^{-1} $Month^{-1}$)
Charcoal	290	53	Shrimp	449	413
Poles	180	105	Crabs	211	192
			Fish	443	319

Threats and drivers to mangrove and associated resources

The threats to the mangrove ecosystem were grouped into two categories: Natural and Anthropogenic. Natural threats are associated to climate change, cyclones and storms. Anthropogenic threats include tree cutting for fuel wood and for building material and artificial river runoff. There are evidences that river floods and wave action, due to the storms, are causing infilling and blockage of the mangrove creeks and mangrove roots with sediments, and subsequently causing mangrove tree death. Artificial river runoffs by the dams alter the natural seasonal cycle, causing either reduced or increased amount of water reaching mangrove forests, changing the salinity level of water in the forest, and subsequently causing the depth of the mangrove trees.

Policy recommendations and options for sustainable mangrove use

The study indicated that the levels of exploitation of mangrove and associated resources is sustained, however, 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 exploiting sustainable the associated resources than exploiting the mangrove trees for firewood, charcoal and building material. Hence, the study recommends strongly the promotion of alternative livelihood to cutting 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.

The stands of mangrove in the Zambezi Delta still allows for sustainable harvesting. The study recommends a sustainable mangrove harvesting plan consisting of cutting commercially viable trees (7.5 m height, 2.5m perimeter) for charcoal production, at the rate of 13 trees, producing 20 bags of charcoal per hectare per month. One of the major causes of mangrove forest destruction is the demand for building material. In order to reduce pressure on mangrove for building material the study recommends the promotion of alternative building material, which includes bricks, for the Zambezi delta is rich in clay. In addition, the study showed the negative downstream effects of the hydroelectric dams, recommending the regulation of the river flow to mimic natural seasonal cycle through the dam.

Acronyms and abbreviations

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	Worldwide Fund for Nature – Mozambique Country Office

1. Introduction

This report provides a rough assessment of the economic value of the mangrove ecosystem services and 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. It is against this background, that the WWF-MCO with the support of Blue Forest is undertaking a project on “Application of the Blue Forests methodologies and approaches through small-scale interventions in Mozambique”, under the Blue Forest 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.

The overall objective of the project was 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 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 catalysing 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 societal benefits. The ecosystem services provided by the mangrove in the Zambezi Delta was valuated 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 into the household income of the people living in the Delta was made as to contribute to rising awareness on the importance of the ecosystem to the local communities. The study discuss further, the threats and management issues and alternative livelihoods options to cutting mangrove 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 products)?
- What are the indirect values of different mangrove ecosystem services (e.g. coastal protection and fish habitat)?
- How, overall, 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 result of the perception of the households on the value of mangroves whereas Chapter 7 presents the result of the household income, as obtained from the interviews. Chapter 8 presents threats and drivers to mangrove 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 GEF Mozambique Blue Forest 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, crabs fattening, the establishment of mangrove harvesting blocks and 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 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 so as 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 The Ecosystem Services Assessment

The ecosystem services assessment was led by António Mubango Hoguane, 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 School of Marine and Coastal Sciences was set. The study comprised various stages of research process including scoping, data sharing, reviewing, outreach and dissemination, workshops and field visits were organised with the aim to engage policy makers, practitioners and local communities maximising 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 January 2017.

2.4 Mangrove ecological value – global perspective

Mangroves are marine wetland vegetation that grows in coastal saline or brackish water. 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 and high salt and temperature gradients (Alongi, 2002). Mangrove trees have aerial roots, exposed to the surface, which obstruct the water circulation and thus, fostering 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, 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 ground for important fisheries 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 (Hoguane *et al.,* 1999).

According to Giri *et al*. (2011) the worldwide total area of mangroves, as estimated in the year 2000, was 137,760 km^2, distributed in tropical and subtropical coastal regions, with the 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 km^2 during the period 1999-2002. Mozambique with an estimated mangrove area of 2,677.27 km^2, 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 synthesise 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). Mangrove 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 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 green house gases in the atmosphere and so, mitigating 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, CO_2 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 develops in mangrove swamps. Both the availability of food and protection in the mangrove swamps are the cause for attraction of juvenile (Hatcher *et al*., 1989). The turbidity in mangrove swamps creates 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 kilometre per year. Pauly and Ingles (1986), quoted by Hatcher *et al*. (1989) estimated catch of about 14 tonnes of prawns per square kilometre 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 mangrove 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 1.1 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 1 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 1.1. 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 m^2 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 metres 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) valuated 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. Recognising 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 & Ittekot, 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.

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 Zambézia, which account to 71% of the total mangroves of Mozambique. There are 10 species of mangrove species occurring in Mozambique, and the dominant species are as follows: *Avicennia marina, Bruguiera gymnorrhiz, Ceriops tagal, Rhizophora mucronata, Sonneratia alba; and* the following occurring in minor proportions: *Xylocarpus granatum, Lumnitzera racemosa, Acrostichum aureum, Barringtonia racemosa, Hibiscus filiaceus, Thespesia populnea.* Mozambique has the largest diversity of mangroves on the continent (Temilola and Simard ,(2013); Spalding *et al.* 1997).The mangroves are distributes along the coast, with higher density in the deltas and estuaries of large rivers, being the Zambezi Delta the largest of all. Bandeira *el at.* (2012) pointed out that the Zambezi River Delta mangrove area, estimated at about 100,000 ha, was the largest mangrove stand in whole eastern; and with 8 mangrove species, was considered the high diversity mangrove area.

Saket and Matusse (1994) using Landsat imagery of the period 1973-1992 estimated the 396,000 ha. Later, Fatoyinbo *at al*. (2008) using same method for the period 1973-1992 estimated the total mangrove forests covered in Mozambique at 290,900 ha, 27% lower than previous estimates, suggesting mangrove loss. 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 have 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.

Mangroves and climate mitigation

Bandeira *el at.* (2012) indicated that Zambezi Delta mangroves sequester high carbon stocks, and so, it is an ideal place for developing C credits initiative. Shapiro *et al*. (2015) using land cover change assessment method estimated the mangrove ecosystem carbon stocks in the Zambezi Delta, and concluded that 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 recognised 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 has been seldom referenced works relating the fisheries production to mangrove. 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 is work stated that penaeid shrimp spawn in open sea but they spend their ealier 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 ground 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, bellow.

Mangrove uses

In Mozambique mangrove are harvested for building materials, firewood, fencing, fish traps and for. Ecologically mangroves play an important role as nursery and feeding grounds for many important commercial fish and for medicine purposes. Sitoe *et al. (*1991) indicated that in Maputo bay about 9 234 metric tonnes are harvested annually for building poles. De Boer (2002) quoting Hatton (1995) indicated that an area of 2,000 ha of mangrove was providing 9,200 t of firewood annually. Bandeira *el at.* (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 gymnorrhiz, Ceriops tagal, Sonneratia alba, Rhizophora mucronata* and *Lumnitzera racemosa* are used for poles for building houses; the species *Bruguiera gymnorrhiz, 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 medicine property; the fruits of *Phoenex rechlinata* are eatable and used to make alcohol beverage;.

Mangroves under threat

Mangroves in Mozambique, similarly to mangroves in other part 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, and 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 the 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 as and death of mangrove in the Zambezi River Delta. Barbosa *et al.* (2001) estimated the mangrove deforestation rate in Mozambique at 1 821 ha^{-1} yr^{-1}, with the highest value around large cities Maputo, with 15.2% and Baira, 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.

2.5 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 4.1. 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 provide 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.

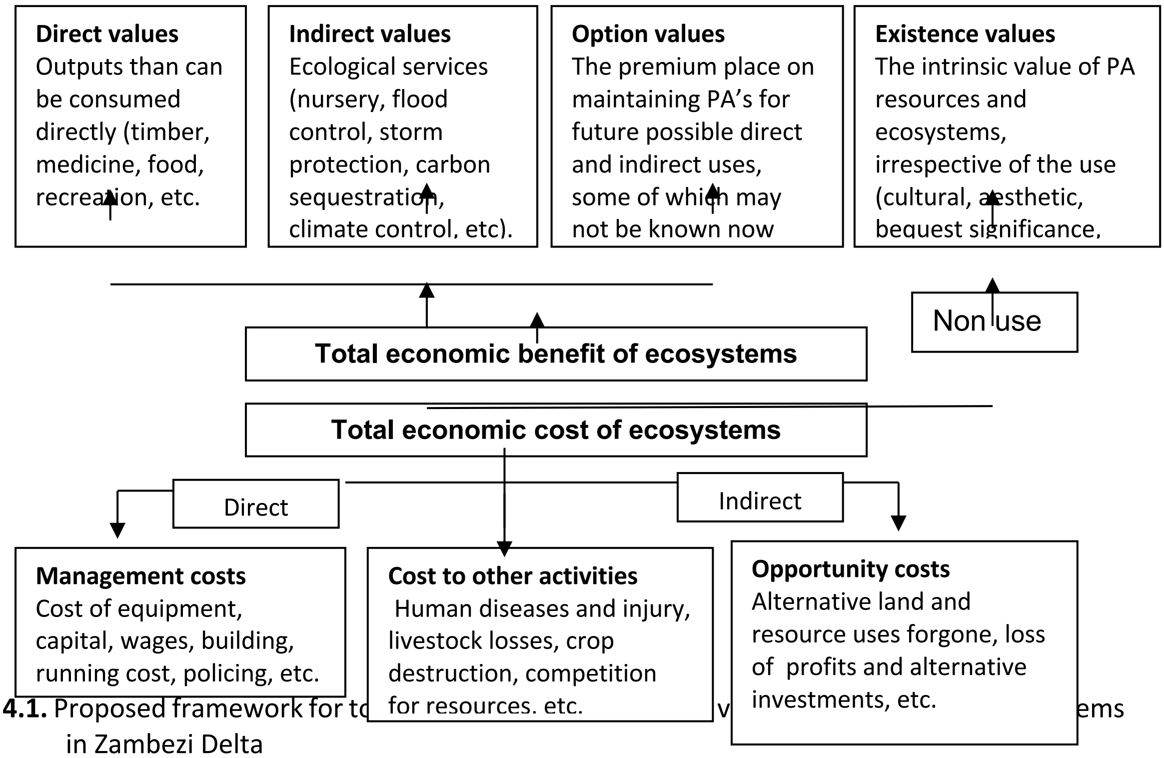

Figure 4.1. Proposed framework for t… v… ems in Zambezi Delta

3. General Bio-physical description of the Zambezi Delta

3.1 General description

The Zambezi Delta is where the Zambezi river enter the Indian Ocean, it is a triangular shaped alluvial plan, 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^o 30’S and 19^o 00’S and Longitudes 35^o 40’E and 36^o 30’E. It covers an area of approximately 12,000 km^2 (Figure 3.1). It has several branches in an area of about 8,000 km^2, 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 and for export, and transport fish and mangrove products upstream. The Zambezi river had played an important role in the transport of people and goods, and so in trade from neighboring countries and overseas.

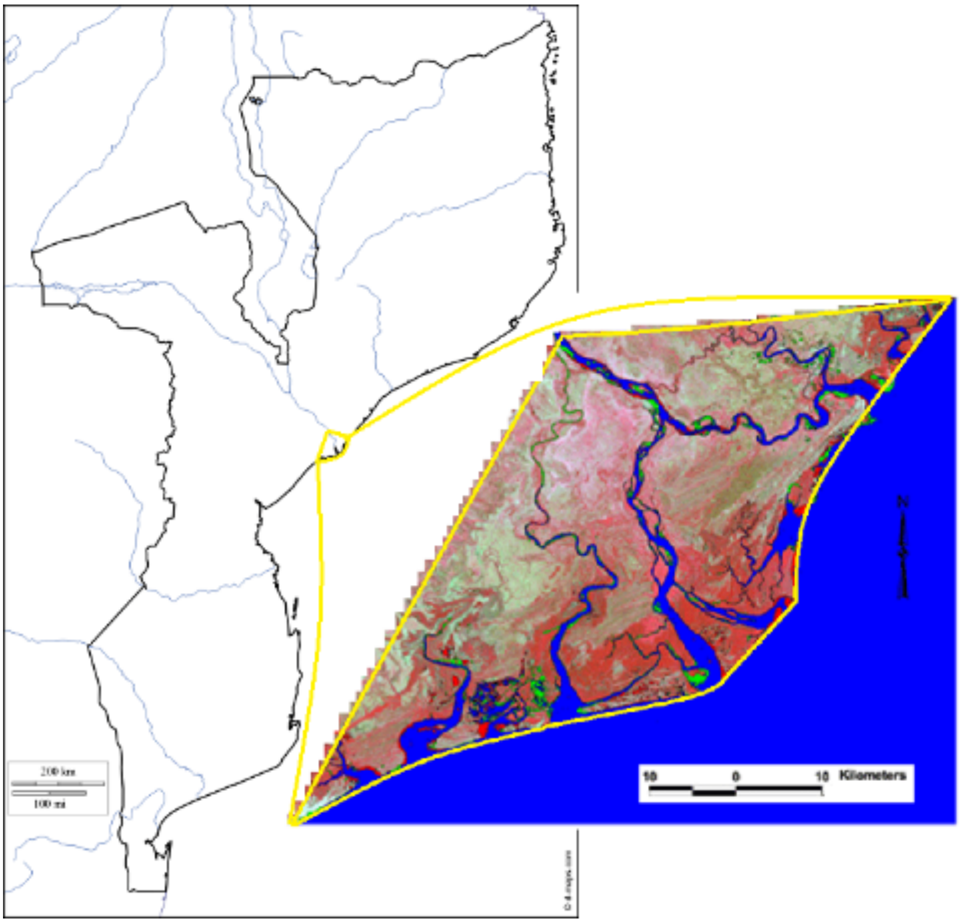

Figure 3.1. Chinde Location Map.

3.2 Hydrology and climate

According to the classification of Köppen, the climate is predominately tropical rain Savannah (BWw) 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 1.1). 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 in East and Southern Africa. The average annual discharge is about 140 km^3 (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 Chabora Bassa, with capacity of generating 2,075 megawatts, in Mozambique. Cahora bassa is the largest dam with storage capacity of 55.8 km^3 (Rendel *et al*. 1980) and it was operational since 1974. The maximum flows at the hydrological station over the Dona Ana Bridge in Tete were mostly over 10,000 $m^3 s^{-1}$ before the regulation, and dropped to about 5,000 $m^3 s^{-1}$ 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 $m^3 s^{-1}$. After the regulation, the maximum flows were mostly below 5,000 $m^3 s^{-1}$, 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.

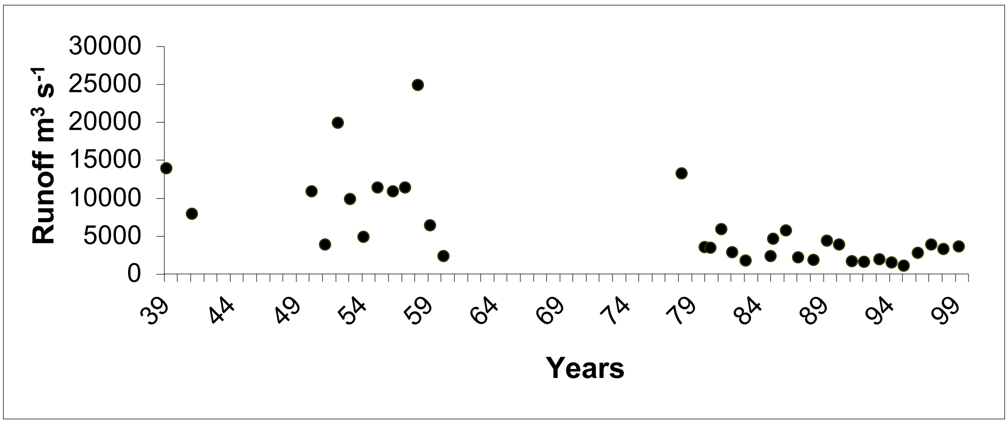

Figure 3.2. Annual maximum runoff of Zambezi River observed at Tete runoff gauge station.

The Zambezi river runoff is said to have positive influence the 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 favourable 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 dam 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, they allow increased runoff during the dry season than 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 superflood 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 if Sofala Bank.

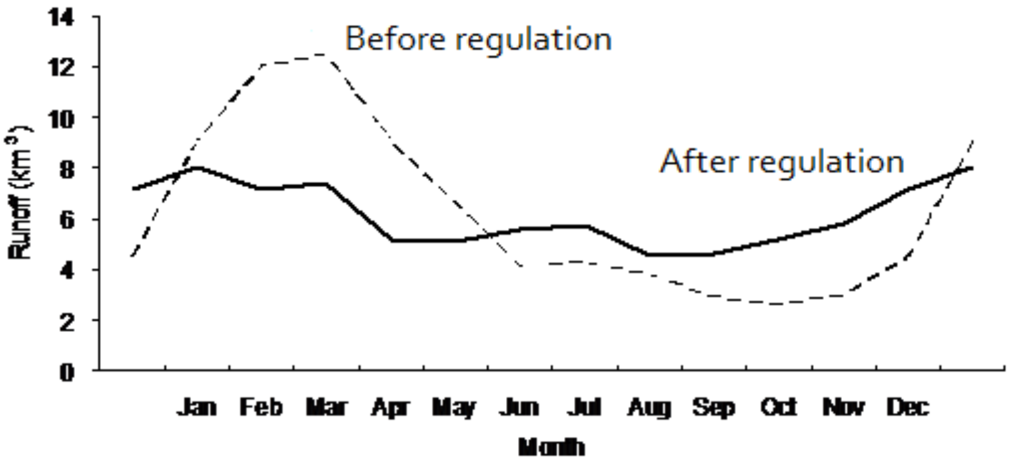

Figure 3.3. Seasonal variation of the Zambezi runoff: before (dashed line) and after Oceanography (thick line) the regulation.

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 Hoguane, 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 sec, 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 characterised by NE current, following along the coast towards the north (Sætre e Jorge da Silva, 1982). Occasionally it flows south, presumably due to with 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. 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 month 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 temperature above 27°C. This watermass is believed to outwell from a shallow tributary.

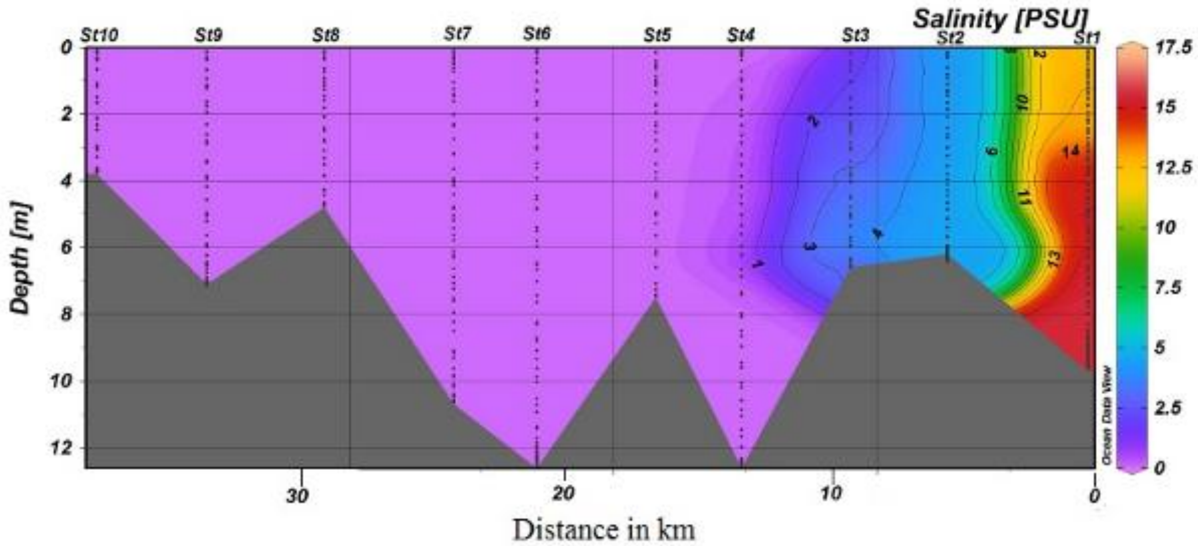

Figure 3.4. Longitudinal salinity profile of the Zambezi delta, during October 2016.

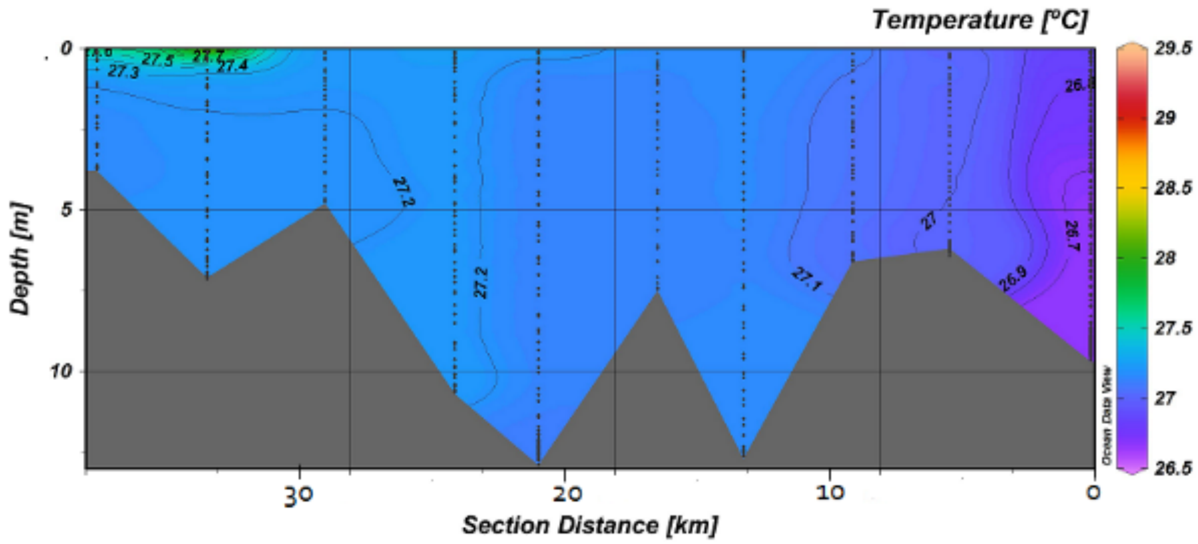

Figure 3.5. Longitudinal temperature profile of the Zambezi delta, during October 2016.

Based on studies of 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 20-40 g s^{-1} and of ammonia was 15-30 g s^{-1}, during the low water, suggesting that the river is the source of these nutrients (Figure 3.6).

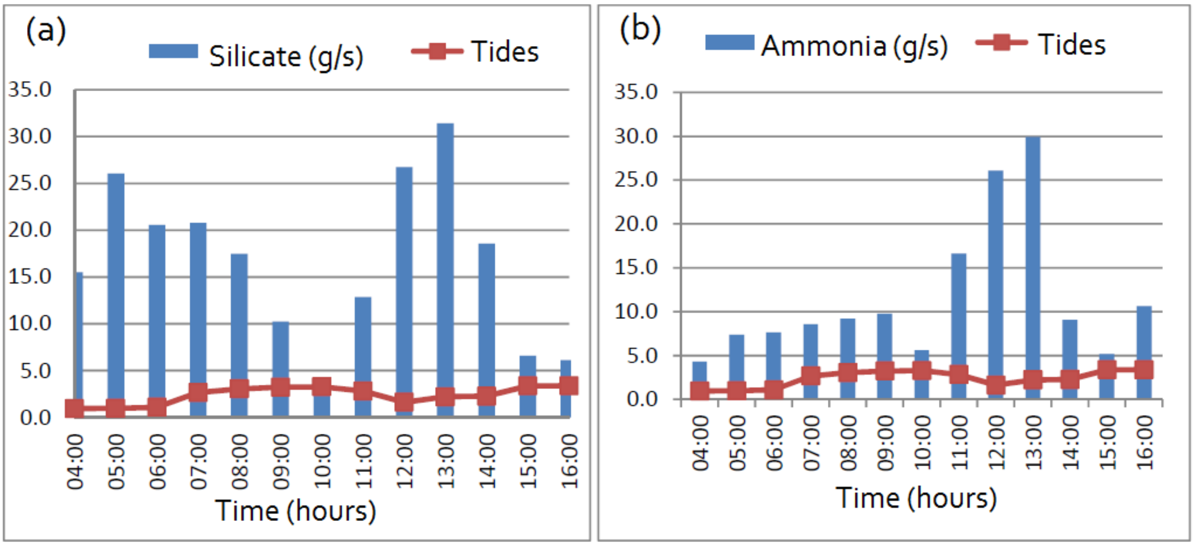

Figure 3.6. Silicate (a) and ammonia)b) concentrations in the mouth of Zambezi river during dry season, July 2014.

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 trapping 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 period. 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 braches 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 cost towards the inland the soil is structured as follows: (a) cleyey soils of aluvial deposits; (b) sand soils of mananga combined with yollowish sand soils in the interior dunes; (c) sand soils combined 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 savannhah 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 characterised by coastal dune vegetation. The savannas woodlands are dominated by Acacia, palms, 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 vegation. 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, 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 hyen (*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.

1.1.1. 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 area crabs of specie *Scylla serrata* (Piatek, 1981). The small pelagic 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).

3.7 Demography

It is estimated that there is about 188,206 people, from 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.

3.8 State of mangrove conservation

The Delta has extensive coastal mangroves, estimated to be 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

In 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.

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 a new mangrove stand (about 4 years old) the density of mangrove trees were 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.

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 create enabling 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 tress to grow. The rate of forest regeneration in a new mangrove stand is as high as 99%.

3.9 Mangrove use

The mangrove creeks and estuary provide important spawning grounds for riverine and oceanic fish species, and so, nourish the fisheries, 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 involve mangrove cutting.
- Exploitation and use of resources provided bay 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 population 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 lend 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 see that they cut mangrove at about 40 cm to 100 cm height from the ground, allowing for regeneration.

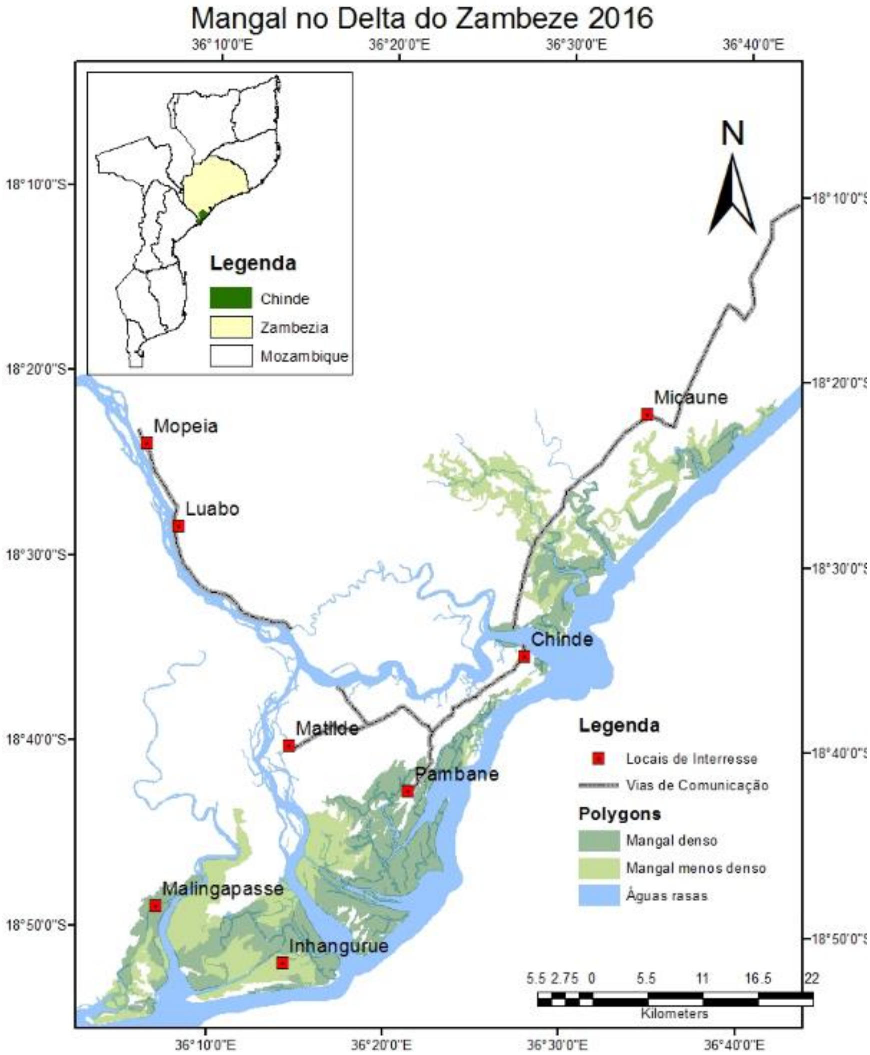

Figure 3.7. Mangrove cover in the Zambezi delta as estimate based in satellite imageries of 2016.

Figure 3.8. A location where mangrove were cut for charcoal production.

Exploitation of the resources provided by mangrove ecosystem services

The major resources are fisheries 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 cost against erosion, carbon sequestration. Further, the mangrove creeks and estuaries are used for maritime transport and in addition mangrove swamps are used by local communities for traditional rituals.

3.10 Livelihood activities in the Delta

The major livelihood activities in the Delta are as follows:

- Agriculture
- Fishing
- Mangrove forest product harvesting

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

During the survey it was noticed that direct mangrove harvesting is mainly practiced by women while men go for fishing. The primary activity of women is agriculture, and so, mangrove harvesting is practiced to supplement the house income.

4. Methodology

The aim of this study is to estimate the economic value associated with mangrove and the economic benefits that can be harness 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. To achieve that a survey based evaluation method, focusing on resources of value to livelihoods, assessing non-market as well as market values, and involving communities was applied. 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 ecosystem was evaluated using market price from the primary producers. The study focused in the following **direct benefits** of mangrove ecosystems, which are the most use 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 have 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 was obtained in the Chinde district and surroundings, Malingamasse in Marromeu, Luabo and Micaune. The household survey was conducted to estimate the contribution of mangrove the products and those derived from mangrove ecosystem services in the house hold 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 were collected:

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

4.2 Survey locations and the size of survey sample

The surveys were conducted in the suburbs, villages, markets and artisanal fisheries centres 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 sites surveyed are presented in Figure 4.1., and were as follows: Chinde –Aeroporto, Chinde – Hospital, Chinde –Amarelo, Chinde –Arrozal, Chinde –Inhalume, Chinde – Fina, Matilde, Pambane, Inhagurue, Luabo, Malingapanse, and Micaune – Tivarone. Table 4.1 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:

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

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.

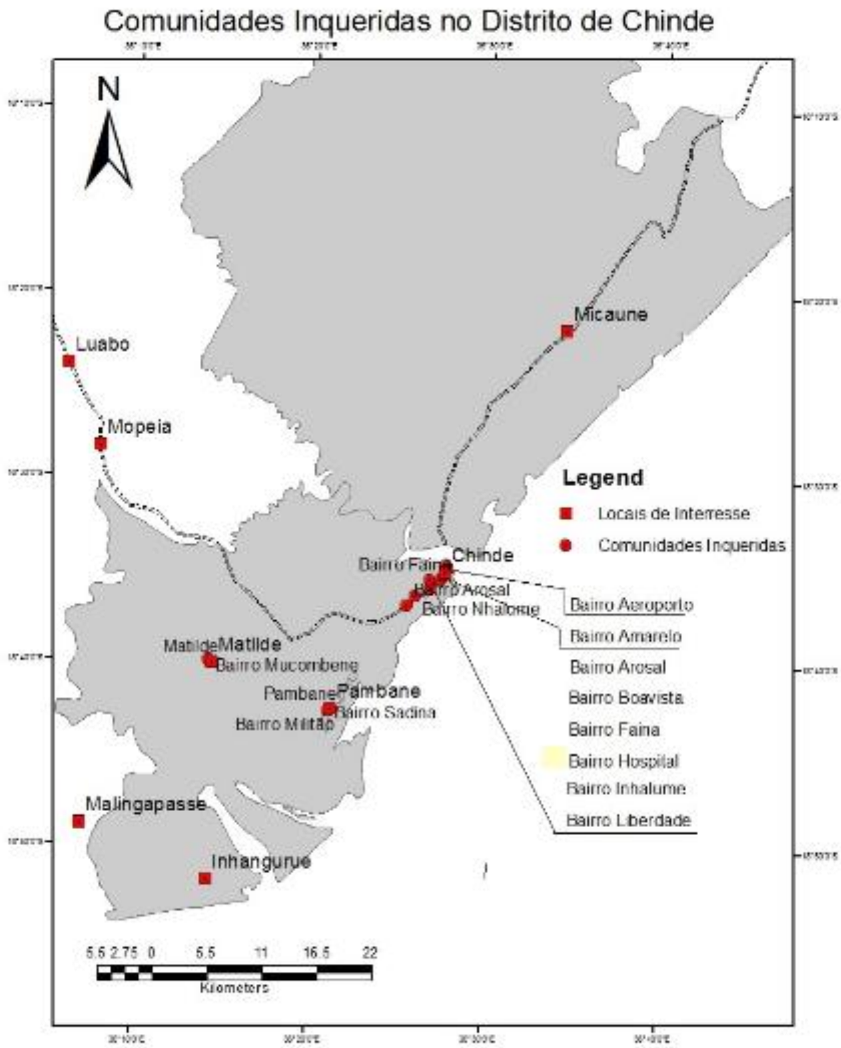

Figure 4.1. Locations surveyed.

Table 4.1. The coordinates of the villages surveyed.

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

4.3 Economic ecological value of mangrove in Zambezi Delta

The present Chapter reports the result of the estimate of the value of the ecosystem services provided by mangrove 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 standardised 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 Mtn. 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 specified ecosystem service attribute are divided by the corresponding area in hectares to obtain a value per hectare. Values reported in per person or house hold terms are converted to a 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, fuel wood, 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

4.4 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 makes 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**
Xilocarpus granatum	Murrubo	Charcoal
		Furniture
Ceriops tagal	Mucandara	House building
		House building
Soneratia alba		Charcoal
		Furniture
Avicennia marina	N'vethe	House building
		Charcoal
Heritiera litorales	Ncolongo	Furniture
Burguiera gyminoriza	Pau ferro	House building
Ryzophora mucronata	Nanthazira	House building

Figure 5.1. shows some furniture built with *Xilocarpus granatum* mangrove wood 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 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) woods of *Xilocarpus granatum* piled up for charcoal stove, (b) a charcoal stove burning and (c) a bag of charcoal produced. (Bairro Aeroporto, 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).

4.5 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 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 7.5 m height, 2.5m perimeter, an ideal forest density of 1800 per hectare, a charcoal efficiency of 20 bags in 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 150MTn per bag of charcoal it gives a total of 3,000Mtn, 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 mangrove, 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 used as poles for building, the tree can be harvested in 5 year, at the rate of 26 trees per hectare per month. Each pole can be sold at 100Mtn, hence, earning 2,600 Mtn, 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, thought it would require up to 20 years to 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 commerce of furniture is not developed in Chinde. According to Gan (1995), roughly 1,050 ha of forests are clear felled annually over a 30 year rotation cycle, with an average yield of 17.4 tons ha^{-1} yr^{-1}.

4.6 Protective function

The village of Chinde is eroding at the rate of 30 m per year (Hoguane and Tauacale work, unpublished data) in a section of about 1,500km along the beach (Figure 6.5). Based in the local testimonies the erosion may have been initiated when in late 80’s many people fled into Chinde Island seeking refuge from civil war. Thoughtfully 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 build a sand barrier along the beach, which creates a protection and enabling environment for settlement of mangrove seeds. Subsequently, there are strips of flourishing mangrove forests, parallel to the coast.

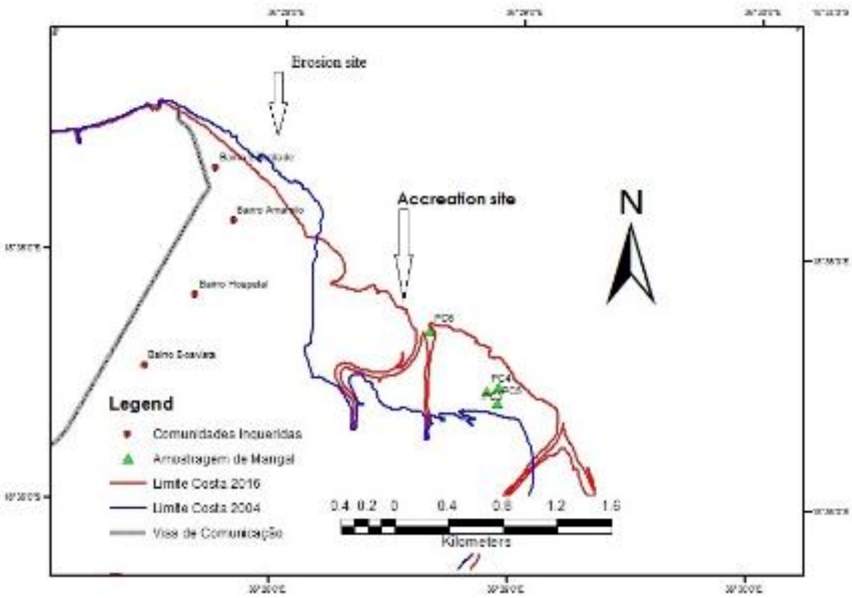

Figure 5.5. Erosion and accretion in the Chinde Beach.

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

Figure 5.6. View of the extent of erosion in Chinde beach.

Various attempts to prevent erosion were tried all with no success. The Government with the support of NGO's organized the communities to set 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 enabling environment for the mangrove seeds to settle and grow. All these attempts did not render the desired result. The erosion continued.

Currently any extension of 1,500 m along the beach with 300 m with is being threatened by erosion (Figure 5.7), putting in danger the following infrastructures: new infrastructure composed of a harbour (Figure 5.8) and a building for maritime administration (Figure 5.9), 3 warehouses, 8 conventional brick houses (Figure 4.10) and about 380 combined timber and cement houses (Figure 5.11) threatened by erosion.

Figure 5.7. Area adjacent to Chinde Beach threatened by erosion.

Figure 5.8. An harbour being build in Chinde.

Figure 5.9. The building for maritime administration in Chinde.

There are a number of houses, estimated at, also treated by erosion. Typical house is illustrated in Figure 14 and are estimated at US$1,600.

Figure 5.10. A brick house in Chinde.

Figure 5.11. Typical house in Chinde.

4.7 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 400-500 m width and 1,500 m 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 mangrove 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 of the infrastructure threatened is as follows: The harbour and the building of maritime administration is estimated at 17,439,383.80 MTn, which is equivalent to about US$581,312.79; the warehouses are estimated at 2,000,000.00MTn, equivalent to US$65,000.00 each; the brick houses are estimated at 800,000.00 MTn, equivalent to US$25,000.00 each and combined timber and cement houses are estimated at 40,000.00MTn, equivalent to US$1,300.00. Table 5.2 summarises the total coast 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	Unit price	Amount	
		MTn	MTn	US$
Harbour 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 30MTn to a dollar.

Considering that a strip of mangrove of 1,500 long and 500 m width, giving an area of 750,000 m^2, would be sufficient to prevent erosion in Chinde, then the value of mangrove protection would be about 60.00MTn per square meter, or about 600,500.00 MTn 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 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, mangrove 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 20- or 100-m wide mangrove belt would be sufficient to protect against tsunami waves of 3- and 6-m in height, respectively. Mazda *et al*. (1997) estimated that mangrove forests as wide as 1000 m might 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 30 m of the edge, while in low-density mangroves it would require much wider vegetation cover to obtain same result (Komiyama *et al*. 2008; Massel *et al*. 1999). Koch *et al*. (2009) assuming a mangrove extent along a 10 km 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) valuated 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.

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 5.12.). However, it was not possible to assign economic value because there were no houses nearby the places where bent mangroves were spotted.

Figure 5.12. Leaned mangrove proving the effect of the storms along the beach.

4.8 Habitat and nursery

Mangrove provide breeding, spawning and nursery habitat for 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, nursing and feeding.

Given the fact that for species caught in the coastal waters either by artisanal, semi-industrial and industrial fleets is difficult to trace which mangrove are related to, 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).

A Table 5.3 presents the catch and catch species composition of the artisanal, semi-industrial and industrial fisheries in Sofala Bank. The species captured are related to mangrove as described in FishBase bay Rainer, and Daniel Pauly (2014) and in the *Encyclopedia of Fishes by Gareth (1998) as follows:*

- Penaeidae shrimp are found in offshore waters on sandy bottom at depths of 20–40 meters. The larvae move towards the coast, enter estuaries and mangrove swamps which serve as nursery ground. They 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. Lives in the 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 *el 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. 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. In 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 waters 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 includes 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 are occur in brackish water. They immigrate 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, 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. 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 the 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, occurs in various inshore habitats: sand or mud bottoms, reefs, estuaries and harbours.
- 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.

4.9 Economic value of the habitat nursery services of mangrove

Table 5.3 present the catches of mangrove related fish species (those that nurse, bread, 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, totalling 58,468 tons of fish per year. The Penaidae 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 speceis, followed by Clupeidae, Sciaenidae and Ariidae.

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 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 5.3. Catch in Sofala Bank in 2014.

		Artisanal		Semi-industrial		Industrial	
Commercial category	**Species family name**	Catch (Tons)	%	Catch (Tons)	%	Catch (Tons)	%
	Penaeidae	1,197	4	170	4	5,031	20
Shrimp	Sergestidae	299	1				
	Portunidae	23	0	126	3	1,006	4
Crab	Others					201	1
	Engraulidae	3,949	13	744	17	4,427	18
	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
Fish	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	
	Sepiidae					528	2
Cephalopoda	Loliginidae					201	1
Rays						327	1
Sharks		145	0				
Other fish		2,394	8	525	12	5,433	22
Total		**29,370**	**100**	**4,454**	**100**	**25,105**	**100**

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

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

Fish product	Quantity (Tons)	Unit Price (MTn/Ton)	Total Price (MTn)	US$
Penaide Srimp	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 dependant 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.

4.10 Carbon Sequestration

Mangrove forests have the ability to sequester carbon from atmosphere and store in soil and in dead roots (Alongi, 2014), contributing to reduce green house 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 sequesters about 463 Mg ha^{-1} yr^{-1}. The figure falls within the findings in other mangrove ecosystems of the world. According to McLeod (2011) the average world carbon burial rate for mangrove was estimated at 2.26 tC 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 mangrove can be sold through 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 CO_2, according to Carbon Planet, one of the leading carbon credit traders. Hence, the carbon sequestered by the mangroves in the Zambezi Delta 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.

4.11 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 mangrove.

4.12 Maritime 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 5.13. In the delta operate about 38 boats and canoes licensed for passengers and goods transports. Figure 5.14 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 meticais equivalent to US$64,000 per year on the transport of passengers and about 6 million meticais, equivalent to US$200,000 per year on the transport of goods.

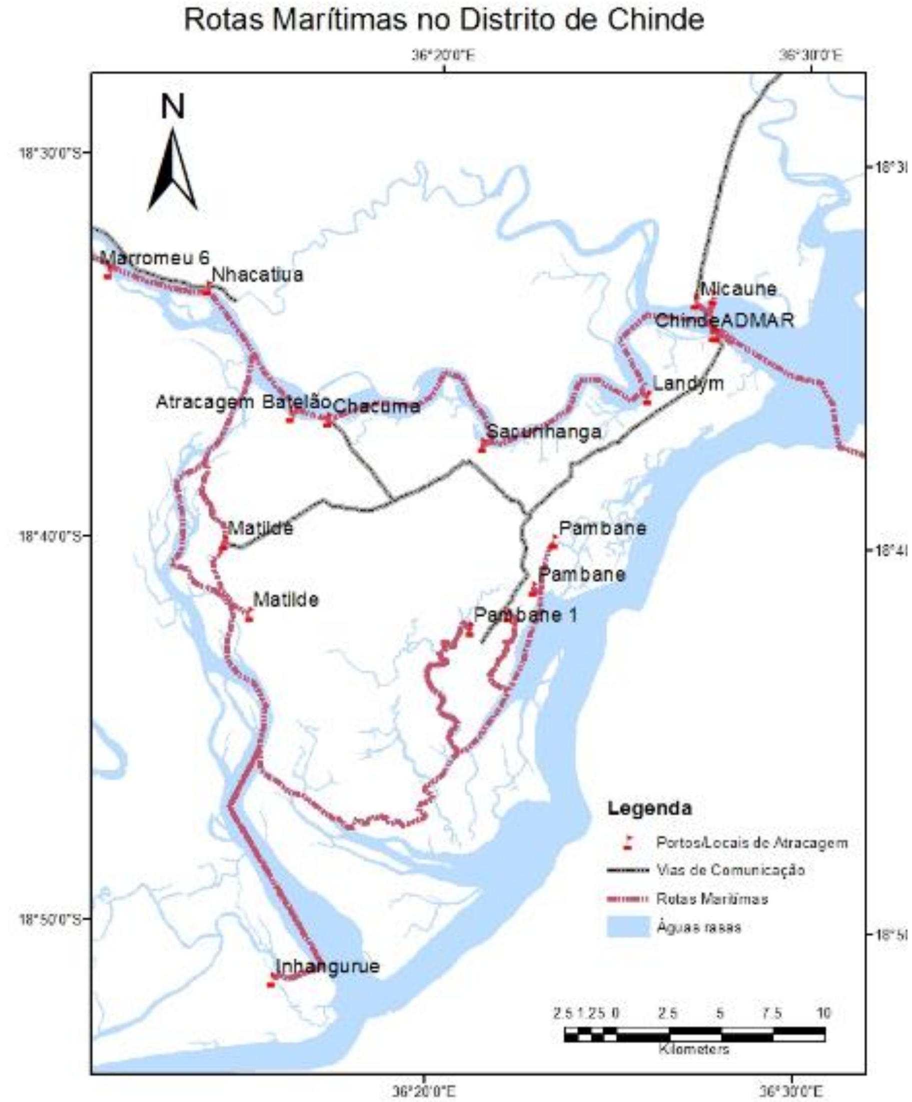

Figure 5.13. Major routs maritime and inland waterway in the Zambezi Delta.

Figure 5.14. A boat used for transport of passengers and goods in the delta.

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

Maritime routs	Passengers Unit price (MTn)	Number	Total income (MTn) (MTn)	(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**

1.1.2. Perception of the households on the value of mangroves

About 573 household (Table 6.1.), from which about 22% were women, distributed in 12 villages (Figure 4.1 and Table 4.1) 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].

Table 6.1. Villages surveyed and number of households interviewed.

Village	No of people 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
Malingapanse	23
Micaune - Tavarone	32
Total	**573**

4.13 Occupational profile

The primary activities indentified were those related to mangrove harvesting for timber, firewood and charcoal production; fisheries and agriculture and the combinations of two or three of primary activities and others. The category of others includes 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 almost all the household, and often not reported, perhaps because since it is not considered as income generating activity it is overlooked in the household income. Figure 6.1(a) presents the livelihood activities per surveyed village. The most practiced activities are fisheries and agriculture and the combination of mangrove harvesting and either agriculture or fisheries. Relatively high proportion of mangrove harvesting for timber and firewood and fisheries were recorded in the villages located near the mangrove and the ocean, such as Chinde Village (Amarelo, Fina, Arrozal), Matilde, Inhangurue, Pambane, the main livelihood actitivity are fisheries and mangrove harvesting, whereas the villages located far away from the mangrove and the ocean, such as Luabo and Malingapasse are mainly agricultural. Higher proportion of others activities were recorded near the highly densely inhabited villages such as Chinde Village (Amarelo, Fina, Arrozal) and in Luabo. In overall the most practiced activities in the delta are fisheries, agriculture, charcoal and others, which includes trade and arts and crafts (Figure 6.1(b)).

4.14 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 in 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 requires more physical effort compared with the agriculture. Fisheries involve going at sea or estuary earlier in the morning and work all day and sometime during the night, exposed to weather hostility; trade most involve 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 per livelihood activity.

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

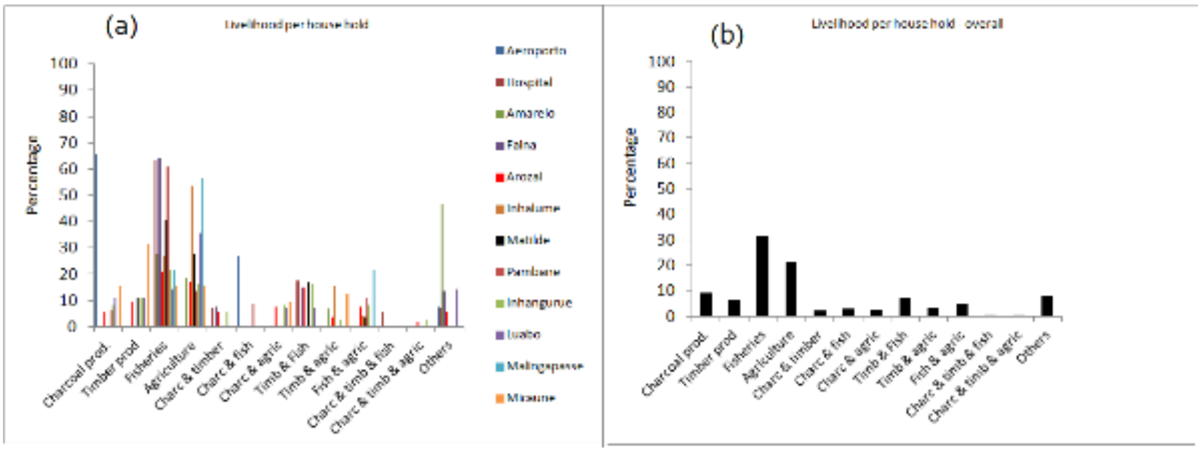

Figure 6.1. Occupational profile of the population in the Zambezi Delta.

4.15 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. In overall women are involved in agriculture, charcoal production and combination of mangrove harvesting and either agriculture and fisheries activities (Figure 6.2(b)).

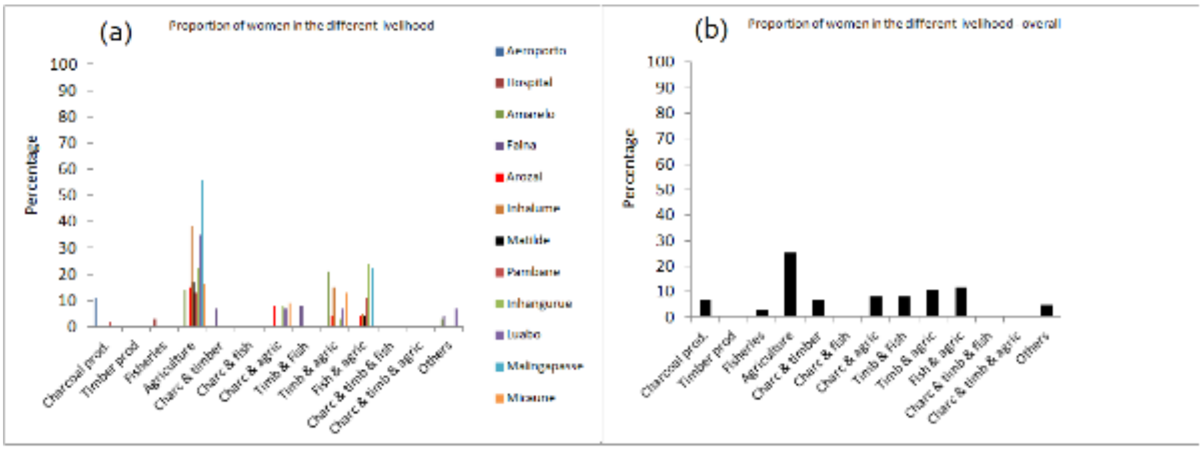

Figure 6.2. Proportion of women involved in each livelihood activities in the Zambezi Delta.

4.16 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 were primarily addressed to those harvesting mangrove for timber, firewood and charcoal for living but it was also addressed to those living by 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 would prefer to go for agriculture (45%), other for fisheries (13%) and trade (15%); few said would practice honey production (8%) and a significant proportion said to have no other alternative (10%). Most of the fisherman 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 an already practiced by the villagers. Surprisingly aquaculture was not a wide option, perhaps because it is an activity not well known in the region. In overall the most preferable alternative livelihood options are agriculture, fisheries, trade and beekeeping (Figure 7.3(b)).

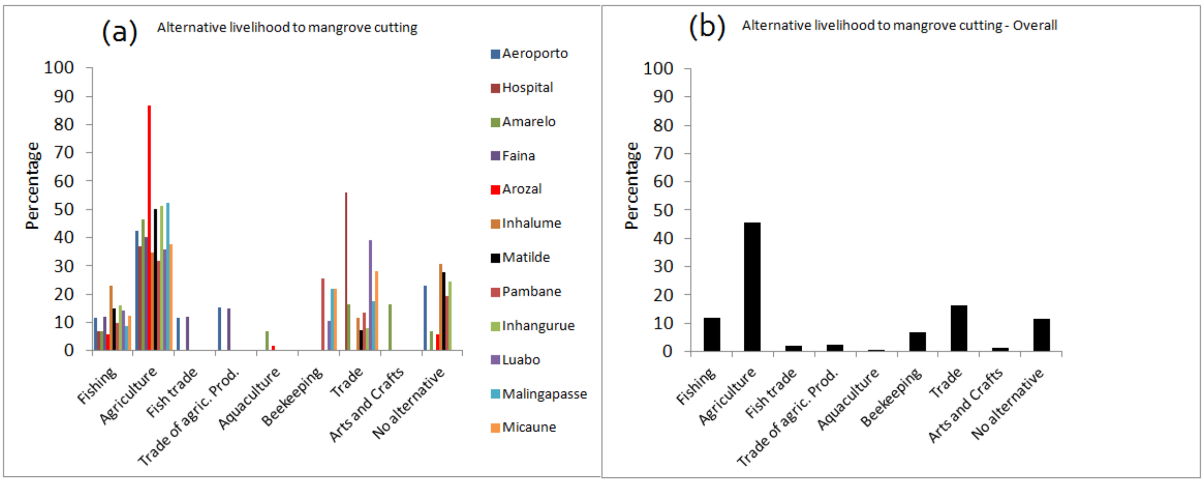

Figure 6.3. Household perception on the alternative livelihood activity in the Zambezi Delta.

4.17 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, fuel wood, 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 that 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 bellow, for each category of the mangrove services.

Mangrove as timber and building material provider

Almost all the household interviewed said they were aware those 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, 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)). In overall nearly 95 percent of the interviewed said that are aware that mangrove provide timber and building material and ranked the service as very important to in their livelihood (Figure 6.4(b)).

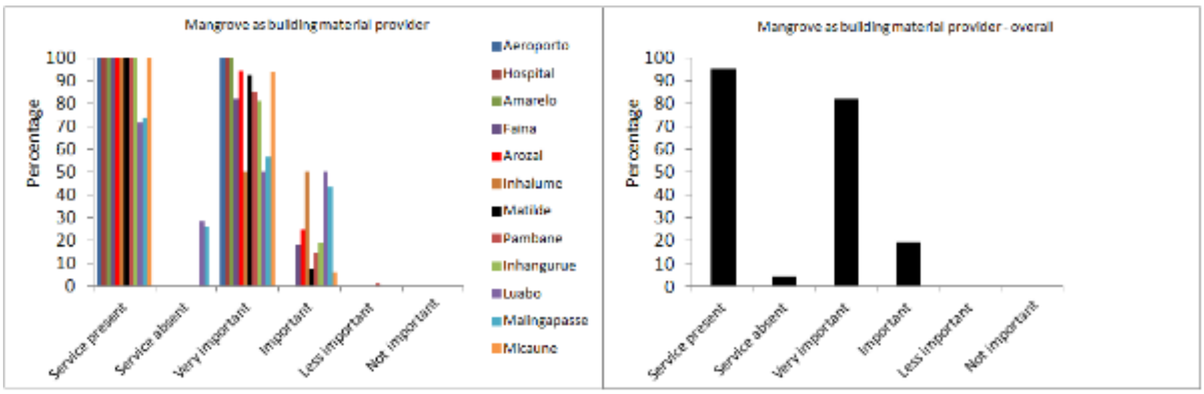

Figure 6.4. Household perception on the mangrove as provider of timber and building material in the Zambezi Delta.

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. In 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)).

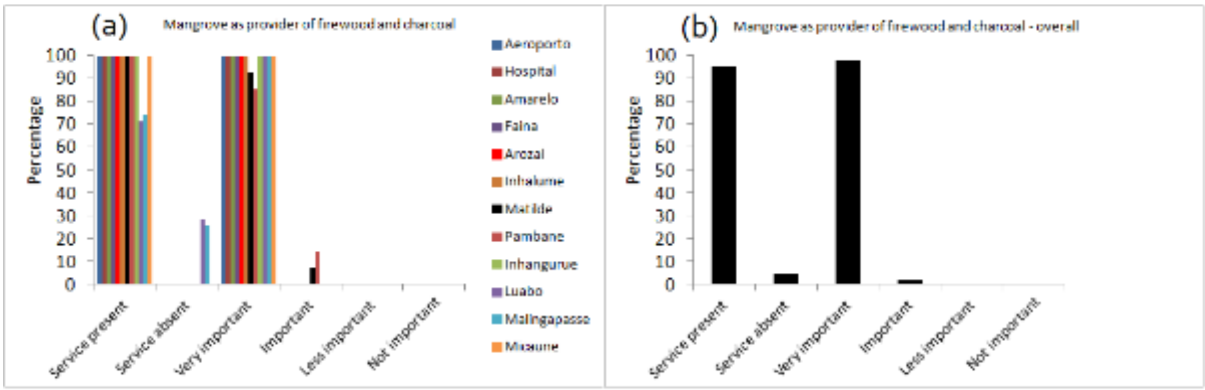

Figure 6.5. Household perception on the mangrove as provider of firewood and charcoal in the Zambezi Delta.

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 way from mangrove, 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. In overall, however, most of the interviewed were aware that mangrove provides food and the service was very important to important to their lives (Figure 6.6(b)).

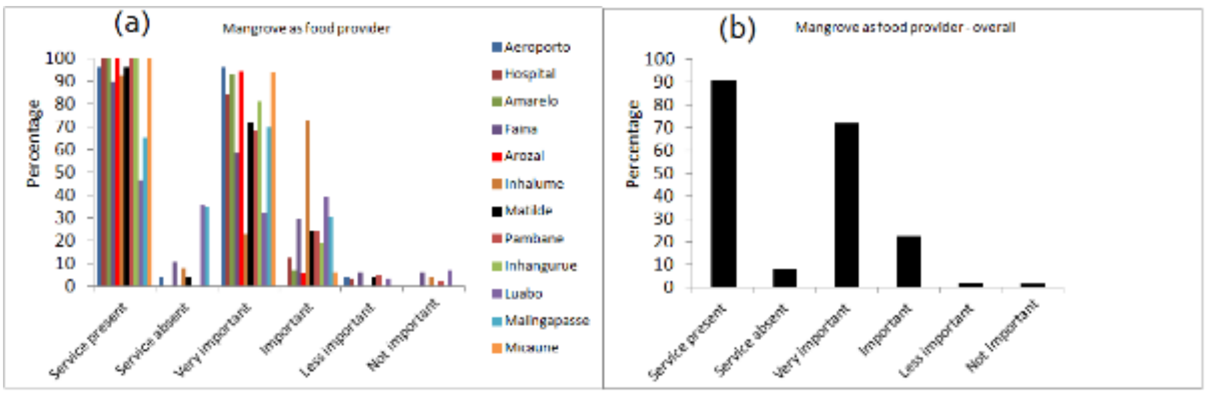

Figure 6.6. Household perception on the mangrove as food provider in the Zambezi Delta.

Mangrove as fish provider

The question meant to assess whether the interviewed were aware of the ecological role of mangrove, 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.

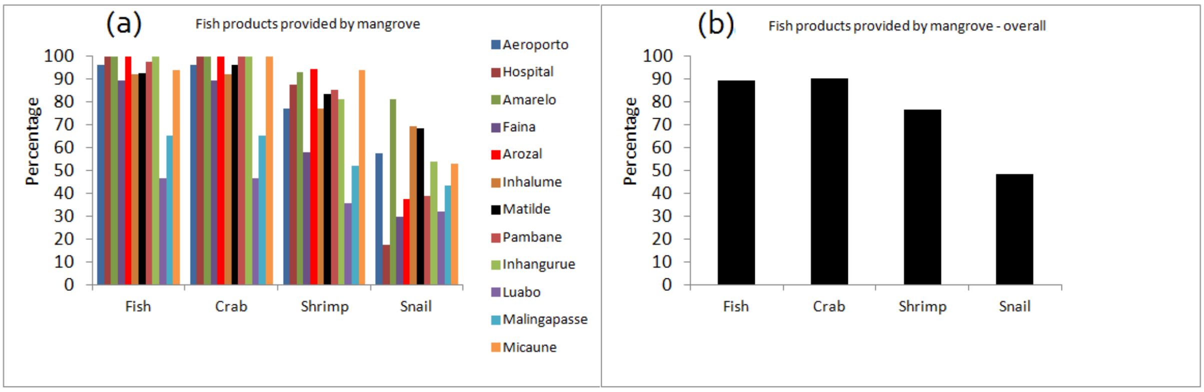

Figure 6.7. Household perception on the mangrove as fish products provider in the Zambezi Delta.

Mangrove as honey provider

The household were asked if they knew they could keep bees and produce honey in mangrove. There was a significant proportion of household aware of the fact that they could practice beekeeping in mangrove, and a quite a 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 know practice for them and they practice in the terrestrial forest. In overall about 60% of the interviewed household 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)).

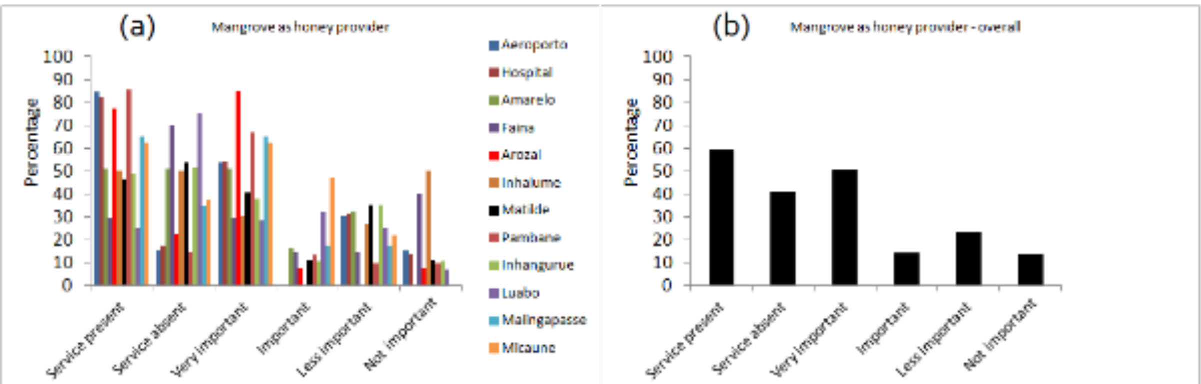

Figure 6.8. Household perception on the possibility of practicing beekeeping and producing honey in mangrove in the Zambezi Delta.

Mangrove as coastal protctor

The question meant to assess whether the interviewed were aware that mangrove can protect the coast against erosion and storms. Most of the interviewed showed that 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. In overall the interviewed were well aware that mangrove provides protection against erosion and buffer to storms and ranked the service as very important to important to their lives (Figure 6.9(b)).

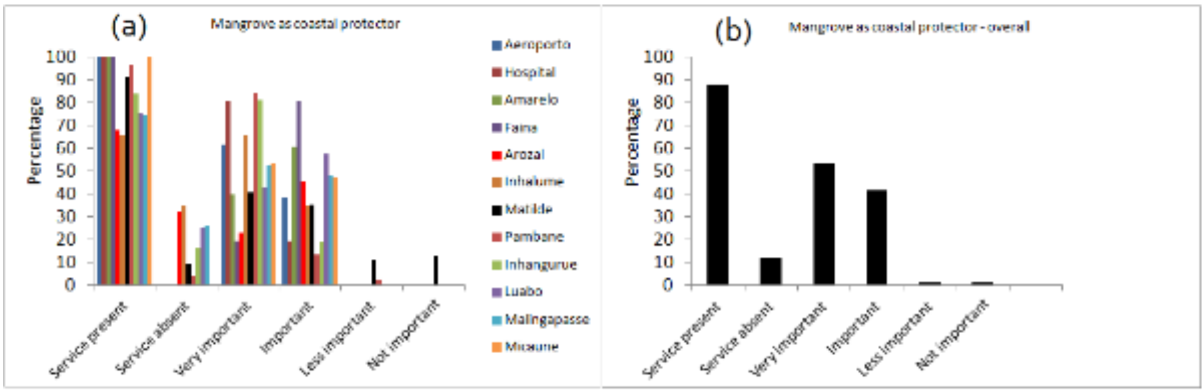

Figure 6.9. Household perception on the role of mangrove on protecting the coast against erosion and storms in the Zambezi Delta.

Mangrove sites used for cultural and rituals ceremonies

Mangrove sites are used for traditional rituals, where the elders go and pray for the goods 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. In overall nearly 70% of the household interviewed said the services 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)).

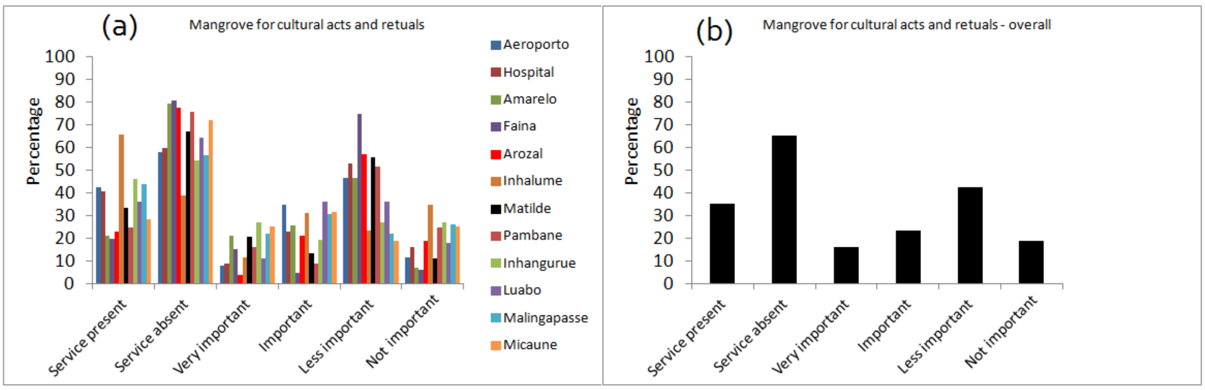

Figure 6.10. Household perception on the use of mangrove sites for cultural and traditional rituals in the Zambezi Delta.

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 the 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. They said that they obtain medicine to cure different diseases, such as wounds, infections, dysenteries and constipation. In 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)).

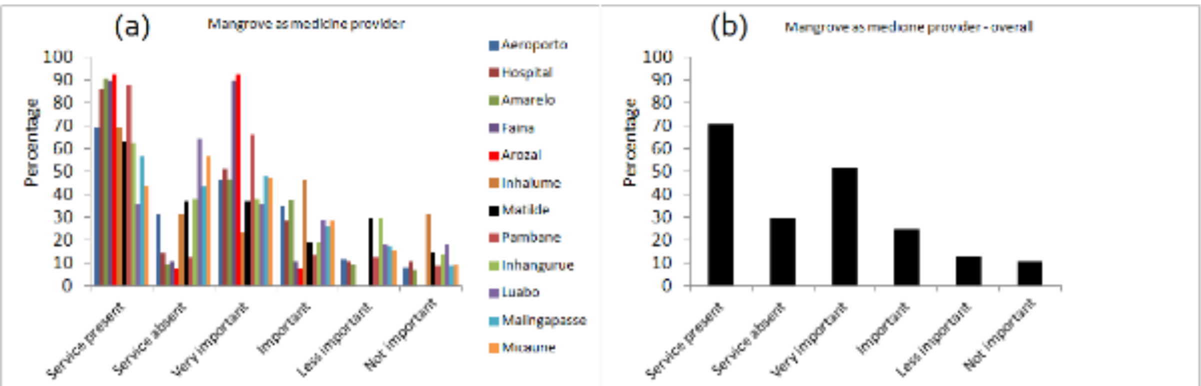

Figure 6.11. Household perception on the mangrove as source of medicine in the Zambezi Delta.

4.18 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 labour our financially for mangrove restoration. The result is presented in Figure 6.12. Most of the interviewed agreed to contribute in labour 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 labour to do in their free time, i.e. after they hay day-to-day work for their livelihood. Very few said they would not contribute for mangrove restoration because they believe mangrove grow naturally. In overall nearly 90% expressed their willingness to contribute for planting mangrove in the entire Zambezi Delta.

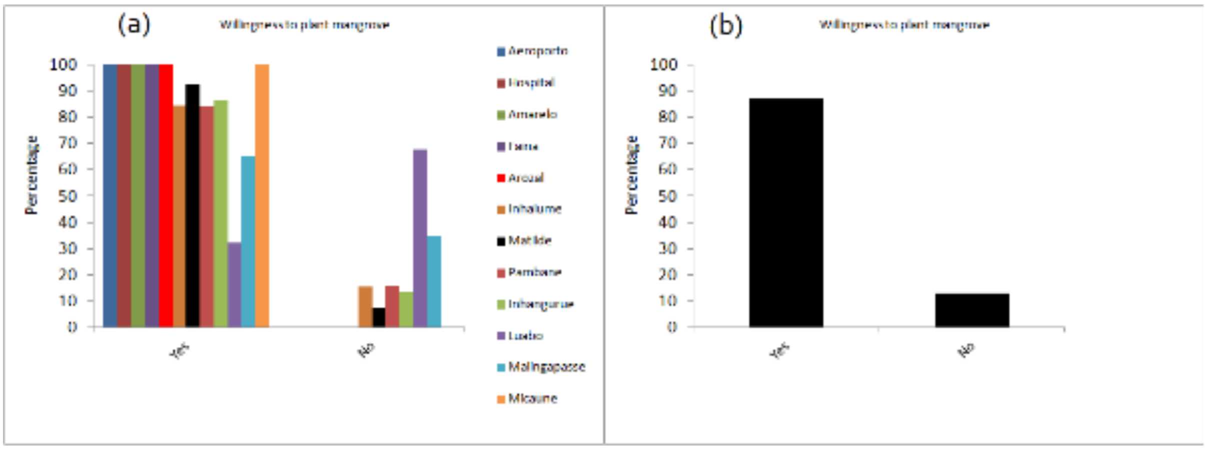

Figure 6.12. Willingness to contribute to restore mangrove in the Zambezi Delta.

1. Household Income

Based in the interview result and in the census of 2011 and strategic planning of 2005 of the District of Chinde and District of 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 product harvesting 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 present 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)**		**Resources obtained from ecosystem services (kg)**		
	Bags of charcoal (0.105 m^3)	**Poles (number)**	**Shrimp**	**Crabs**	**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**

1.1. 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 30MTn 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 has the potential to provide more income per household if markets are provide. Currently there are two Tanzanians and one Chinese 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 for export to China. The mangrove related resources contributes significantly to the well being of Coastal population considering the fact that average, from 1980 until 2015, GDP per capita in Mozambique 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. A mangrove trader from chine in Zambezi Delta.

4.19 Net household income

Net household income for charcoal production

The estimate of the cost production of charcoal is presented in Table 7.3. As obtained in during the interviews, the production involve 2 men, working on average two stoves per month, and totalling 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 labour 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 life time of these equipments is estimated at about 3 years. They use about 11 m^3 of wood and produce about 1.76 m^3, equivalent to 32 bags of charcoal. Hence the production cost is estimated at MZN1638 per 32 bags of charcoal, from which MZN38 is the depreciation of the capital and MZN1600 is the labour 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 the charcoal production.

Item	Quantity	Unit value (MZN)	Amount per month (MZN)
Labour (man month)	2men x 40 hours	20	1,600
Capital cost			
- 1saw		- 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 begs	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 involve 1 men, working on average 140 hours per month, and producing on average 50 to 500 poles per month, depending on the size. The labour is estimated at MZN20 per person and per hour. The investment is composed by one saw, 1 blade and 1 axes at the cost of MZN500, MZN150 and MZN300, respectively, and the life time of these equipments is estimated at about 3 years. The production cost is estimated at 2,826 per month, from which MZN26 is the depreciation of the capital and MZN2,800 is the labour 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 7.4. Estimate of the net household income per month for the pole production.

Item	Quantity	Unit value (MZN)	Amount per month (MZN)
Labour (man month)	1man x 140 hours	20	2,800
Capital cost			
- 1saw		- 500 for 36 months	14
- 1 blades		- 150 for 36 months	4
- 1 axes		- 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 presents the summary of the production cost of poles and charcoal and the net household income per month.

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
Labour (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 8.6. The production involves on average 10 men, working on average 90 hours per month, as it depends on tides. The labour is estimated at MZN30 per person per hour. The capital cost involves seines and boats at different costs (Table 7.7) and the labour which, per each fishing gear, it takes from 3 to 22 persons. Hence, the average production cost is estimated at 26,619 per month, from which MZN4,344 is the depreciation of the capital and MZN22,275 is the labour. 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. These 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. For the crabs the investment is a bade or a hoe at the cost of MZN150, and involves one person, working 80 hours a month at the rate of MZN20 per hour, and 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 house hold 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 per month	Unit cost per person (MZN)	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
Labour (man month)	1,600	800	2800	2,228	1,600	2,228
Capital costs	150	19	26	434	150	434
Total production costs	1,750	819	2,826	2,662	1,750	2,662
Average gross income	7,500	2400	6,000	15,062	7,500	12,237
Net income per household per month	**5,750**	**1581**	**3,174**	**12,400**	**5,750**	**9,575**

5. 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 fuel wood and for building material and artificial river runoff.

5.1 Climate change induced threats

Climate change induced threats influences 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 mangrove 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. Supply of fresh water 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 mangrove are adapted to seasonal freshwater flooding, excessive freshwater can cause death of mangrove. 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 in the severity may cause death to mangrove by salt shortage stresses and by siltation, which again covers the mangrove roots. Figure 8.1 show a mangrove which died by excessive freshwater and flooding in the northern margin of the estuary in the Chinde Village. Apparently the recovering from excessive freshwater and flooding seems to be rather a 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 and causing the death of the trees. The recovering in the circumstances of storms, however, is relatively fast, as the sand dunes set bay storm causes enabling environment for mangrove seeds to fix and grow in a new forest.

5.2 Anthropogenic threats

Artificial river runoffs by the dams alter the natural seasonal cycle, 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 characterised 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 the 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 other 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.

6. 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 mangrove render more to people if conserved, thus, exploiting sustainable the associated resources than when exploiting the mangrove trees for firewood, charcoal and building material, all of which involves cutting of mangroves. Hence, it is strongly recommend the promotion of alternative livelihood 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.

6.1 Options for sustainable harvesting of mangrove

The stands of mangrove 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 suit 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 estimate 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 ther4e is a strong mangrove harvesting fro timber, fuelwood and charcoal.

6.2 Suggested alternative livelihood

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, 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, incoming generating agriculture could be implemented in all the villages; however, the villages with high potential for agriculture are Inhacatiua, Luabo and Malingapasse.

Fish processing and trade

Most of the fish product 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 loosing 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 product 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 as 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 grown up to 800-900g. The technology involves the construct 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 dedicating to crab trade. Currently is being 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 e entrepreneurs in crab trade need also 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 have also excellent facilities for mariculture in cages, and these are as follows: Bairro Hospital, Bairro Amarelo and Bairro Aeroporto, in Chinde Sede and in Matilde and Pambane. This activity would contribute to increase income and to reduce pressure on the natural stocks and ecosystems.

Beekeeping

Beekeeping can be a thriving business. Mangrove forest has potential for honey production throughout the year. Beekeeping is a lucrative business. It can provide for 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. Farther, it may contribute to crop production through pollination process by bees (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 Arozal, 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.

6.3 Alternative building material to mangrove poles

Chinde, and almost throughout the country there are alternative for building to 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 break house in Chinde. The government have 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.

6.4 Sustainable management of the dams

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

7. Discussion

The mangroves in the Zambezi Delta are well preserved with stands of old, tall, wide and dense mangrove trees, despite few and 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. Sustainably harvest of mangroves is being practiced over 120 years in parts of Malaysia and Bangladesh. However, for sustainable harvesting there is a need to establish and maintain a sustainable mangrove management plan. In this study a mangrove management system by which allowed size for charcoal production would be 7.5 m height, 2.5 m perimeter, and allowed harvest would be 13 trees per month per hectare, and providing 20 bags of charcoal per month per hectare, which provides an income of US$100 per month per hectare is thereby suggested. 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 281,074 ha, it would benefit 281,074 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 heath forest there is a need to cut old tress to allow for new trees to develop, the selective harvesting. However, mangrove forests have particular features which make them different from other forests, they are highly dense making it difficult to penetrate and do selective cutting. As a result the people tend to cut them in sequence, clearing the forest as they go along. Further, mangrove tree tend to attain 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 mangrove 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 so that reforestation would require setting up a protection against waves and currents for 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 environment for mangrove seed to settle are established, and thereon new mangrove forest established. The local people are well aware of the protective value of mangrove 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, for in the present study it was used the method of damage avoided, which consists in evaluating the infrastructure at risk, which on turn, depends in the infrastructures available and their value on the local market price. The mangrove on 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 was not possible to estimate the value because there was no valuable infrastructures along the coastal area affected by storms.

Mangrove 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 mangrove ecosystem was made considering the entire mangroves 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 came 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 mangrove caught in Sofala bank, and then integrated to the entire mangrove area.

In the present study the figures of catch and income from fisheries products is considered to be underestimated. The catch statistics of artisanal fisheries are highly underestimated as the fishing centres are scattered along the cost, some located in remote places with difficult access for the samplers. In addition, the some of the artisanal fishermen operate during the night are call the fishing centres earlier morning or in the evening when there is no one to record. Nevertheless, the value obtained in present study of catch income rates per unit mangrove area of 209 kg ha^{-1} yr^{-1} and US$600 ha^{-1} yr^{-1}, respectively, fits 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 Philippines and US$769 ha^{-1} yr^{-1}, for Brazil. Several studies have indicated that the value of mangrove-related fisheries resources ranged from US$ 120–3000 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 sequesters 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, a part from cutting mangroves, to the local people.

People in the Delta are well aware about the importance of mangrove in their livelihood. The income generating is mainly based in mangrove products and mangrove related products. Although agriculture is widely practiced and existence of fertile soils it is practiced only for subsistence. Inquired about alternative livelihood most 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, as to avoid overexploitation of the resources and destruction of the habitat, because restoration often take long time and could be costly. In that regard, alternative livelihood apart from cutting the tree 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 could greatly increase the fish value, reduce losses post harvesting, and increase household income which, in turn, may result in reduced fishing effort; mariculture is another potential livelihood activity suggested. It could include crab fattening and mariculture of fish in cages. Pond aquaculture, which involves digging and destructing 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 as shown clearly that mangrove ecosystem render more to the wellbeing of the people conserved than overexploited. 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.

8. Main conclusions and recommendations for future studies

8.1 Main conclusions

The 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 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 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, obtained from literature and based 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 breading 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 analysing the information since, in most cases, valuation of the impacts of a management alternative on catches on fisheries is based on assumptions that often luck scientific solid evidences, and so, somewhat speculative, due to inadequate knowledge regarding the ecological linkages between mangrove ecosystem and fish populations. Further, the study use 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, was 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 CO_2, according to Carbon Planet, was estimated at US$6,000 per ha^{-1} $year^{-1}$. Table 11.1 summarises the estimated mangrove value of the Zambezi Delta.

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		
	Harvesting rate (No of trees ha^{-1} yr^{-1})	Yield (US$ ha^{-1} yr^{-1})		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 valuate 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 summarises the estimated household income from the mangrove products and mangrove ecosystem services in the Zambezi Delta.

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		
	Gross income (US$ ha^{-1} $Month^{-1}$)	Net Income (US$ ha^{-1} $Month^{-1}$)		Gross income (US$ ha^{-1} $Month^{-1}$)	Net Income (US$ ha^{-1} $Month^{-1}$)
Charcoal	290	53	Shrimp	449	413
Poles	180	105	Crabs	211	192
			Fish	443	319

8.2 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, Birro 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 consider a mature trees 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 planted 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 Cabora 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 well knowledgeable of the value of mangroves and willing to contribute for their restoration and conservation.

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

- Establishment of a mangrove management system and sustainable exploitation of mangrove tree products such that sustainable harvesting 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 wilde stocks and ecosystems in Bairro Hospital, Bairro Amarelo and Bairro Aeroporto, in Chinde Sede and in Matilde and Pambane.
- Promotion of beekeeping in mangroive forest in Bairro Faina and Bairro Arozal, in Chinde Sede, in Matilde, Pambane, Inhagurue and Malingapasse.
- Promotion of the use of bricks, taking advance of abundant clay, for building houses as an alternative to mangrove timber and poles in all the delta.
- Management of the Cabora Bassa dam as to mimic the natural seasonal cycle as maximum as possible.

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Annex – I – Interview Questionnaires

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	Qty/mês	Preço unitário	Preço total/mês
Estaca			
Lenha			
Carvão			

Peixe			
Camarão			
Caranguejo			
Thodwe			
Ameijoa			
Mel			
Ostras			
Total			

Espécies de peixe

Espécies	Qty/mês	Preço unitário	Preço total/mês

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	Qty/mês	Custo unitário	Custo total/mês
Estaca			
Lenha			
Carvão			
Peixe			
Camarão			
Caranguejo			
Thodwe			

Ameijoa			
Mel			
Outros			
Total			

Questionário - 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			
Ameijoa			
Mel			
Outros			
Total			

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 ____

____

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 ____

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 (comercio, pequenas industrias)

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 / Outros	Mangal	Caniço	Alvenaria	Chapas?Tabuas?
Cobertura capim				
Cobertura chapas				
Tamanho				
Duração				
Custo				

Mapa resumo de construções com material de mangal

População total do distrito ____

Masculino ______________ Feminino ___________________

População por faixa Etária: < 18 ________ [18, 35]__________ >35_________

Numero total de casas _________________________________

Tipo de habitação

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

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 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…)

____

____

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…)

____

____

____

Mapa sobre a opinião da comunidade sobre a importância dos serviços ecossistémicos

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 ( )

Fornecimento de material de construção

Você ou alguém que você conhece obtém material de construção 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 ( )

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 ( )

Proteção costeira
Você se 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 ( )