UNIVERSITY OF EMBU

PURITY MUTHONI RIUNGU

MSc

2023

VALUE CHAIN AND SUSTAINABILITY OF MANGROVE WOOD HARVESTING IN LAMU COUNTY, KENYA

PURITY MUTHONI RIUNGU

B521/1235/2018

A THESIS SUBMITTED IN PARTIAL FULFILLMENT FOR THE DEGREE OF MASTER OF SCIENCE IN PLANT ECOLOGY OF THE UNIVERSITY OF EMBU

JUNE, 2023

DECLARATION

This thesis is my original work and has not been presented for a degree in any other university.

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DEDICATION

I dedicate this work to my family for their unwavering support, love, encouragement, and prayers during my study.

ACKNOWLEDGEMENT

I wish to express my sincere gratitude to the University of Embu for the award of a scholarship to pursue my Master's degree in Plant Ecology. I thank my supervisors; Dr. Michael N. Githaiga and Dr. Justin Nyaga from the Department of Biological Sciences, University of Embu and Dr. James Kairo from Kenya Marine and Fisheries Research Institute (KMFRI) for their mentorship and professional guidance, academic support, and encouragement which contributed to the success of this work. I thank the KMFRI management for granting me internship at the research Institute. I further appreciate the Kenya Forest Service (KFS), Lamu County under the leadership of the Ecosystem Conservator, Mr. Evans Maneno for their help in acquisition of archived forestry data and their help throughout the data collection activity.

I thank the entire staff of KMFRI, Gazi sub-station, in particular, Dr. Langat Kipkorir, Dr. Amina Hamza, Virginia Ngei, Lilian Mwihaki, Derrick Muthomi, Gabriel Akoko, Fredrick Mungai, Abel Kiprono and Anthony Mbatha for their mentorship and support during data collection. My stay in Gazi village broadened my interest which subsequently enhanced my understanding of the blue carbon ecosystems especially mangroves. I am also grateful to local residents of Gazi for their hospitality during my stay.

I thank my family; particularly my parents Geoffrey Riungu and Andriana Kagoji for their unwavering love, prayers and support both financially and emotionally. To my siblings Betty Mwende, Franklin Ngugi, Ann Kanjiru, Gilbert Kirimi and Cousin Martin Mwiti. Thank you for your unending support, prayers and love. You have always believed in me. My friends Kipkemboi Bett and Norah Mwendwa, you have been my source of inspiration and motivation. I couldn't ask for more.

Finally, I acknowledge the financial support I received from the PEW Charitable Trust Contract: 00032875, WWF-Germany and WWF-US, contract number BMZ 68776, the WWF-Kenya and The Nature Conservancy's Contract No. F104765 all funded to KMFRI through Dr. James Kairo.

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ABBREVIATIONS AND ACRONYMNS

ANOVA	Analysis of Variance
CIDP	County Integrated Development Plan
CSP	County Spatial Plan
DBH	Diameter at Breast Height
FAO	Food and Agricultural Organization
FDK	Forest Department of Kenya
KFS	Kenya Forest Service
KMFRI	Kenya Marine and Fisheries Research Institute
KMNR	Kiunga Marine National Reserve
KRA	Kenya Revenue Authority
KWS	Kenya Wildlife Service
LAPSSET	Lamu Port- South Sudan Ethiopia Transport
MEA	Millennium Ecosystem Assessment
MoALF	Ministry of Agriculture, Livestock and Fisheries
QC	Quality Class
TEEB	The Economics of Ecosystems and Biodiversity
TEV	Total Economic Value
UNEP	United Nations Environment Programme

UNESCO	United Nations Educational, Scientific and Cultural Organization
VCA	Value Chain Analysis
WIO	Western Indian Ocean

ABSTRACT

Mangrove forests provide harvestable wood and non-wood resources to human society around the world. The current study evaluated value chain of mangrove wood products from Lamu County, Kenya, and how these impacts on resources' sustainability. To assess structure and yield data of Lamu mangroves, stratified random sampling design was used in the different blocks. Quadrats measuring 20 m × 20 m were established along transects, running perpendicular to the shoreline covering different vegetation types. Vegetation attributes measured included species, stem diameter (cm), height (m), and pole quality, from which the stand density (stems ha^{-1}), stand table, basal area (m^2 ha^{-1}), and merchantable stems were derived. *Rhizophora mucronata* and *Ceriops tagal* had the highest stocking densities across the 5 management blocks. The density of merchantable poles for the dominant mangrove species', *Rhizophora mucronata* and *Ceriops tagal* was estimated at 1,361stems ha^{-1}. Results from the market survey show that exploitation of mangrove wood products in Kenya involve several actors, including the national regulator, licensees, cutters, transporters, stockists, and finally the consumers. Based on the differences between allowable and harvest data, Lamu mangroves can be said to be under-exploited. For the 1992-2018 period, an average of 223.5 scores $ha^{-1}yr^{-1}$ of mangrove poles were harvested from Lamu County. During the same period, the harvest data indicate that on averages, 6.2 scores ha^{-1} yr^{-1} of mangrove poles were removed. However, based on stand level data generated as part of this study, mangroves in Lamu County are over-exploited and stocked with non-merchantable poles. There are differentiated net income among various actors in mangrove trade in Kenya. Mangrove cutters are among the 'least beneficiaries' in mangrove trade value chain earning a monthly net income of USD118.6±17.9. The greatest winners in mangrove trade are the Kenya Forest Service, licensees, transporters, and mangrove dealers (or stockists) in urban centers. The findings of this study are critical in development of the harvesting plan for Lamu County mangroves. The results provide insights toward streamlining mangrove trade for community development, revenue generation and environmental sustainability.

CHAPTER ONE

INTRODUCTION

1.1. Background information

Mangroves are trees and shrubs uniquely adapted to intertidal areas of tropical and subtropical coasts around the world (FAO, 2010; Tomlinson, 2016). These 'blue carbon' ecosystems (Nellerman et al., 2009; Macleod et al., 2011) are important for the livelihood of coastal communities as they provide a variety of goods and services, and support national development (Costanza, 2008; Spalding et al., 2010; MEA, 2015). Mangrove provides harvestable wood products to adjacent human society (Kirui et al., 2013; Duke et al., 2014) that utilizes them for building and fuelwood (TEEB, 2010; Constanza et al., 2014; Government of Kenya, 2017; Hamza et al., 2020). Equally, mangrove provides fishery resources, dyes, and traditional medicine that are widely used by coastal communities (Gupta & Roy, 2012; Salem & Mercer, 2012a; Vegh et al., 2014; Lang'at et al., 2014). In Kenya, it is estimated that communities living adjacent to mangrove ecosystems derive some 80% of their wood requirements from the forest (Huxham et al., 2018).

Despite the environmental, ecological, and economic values of mangroves, they are being lost and degraded at an estimated rate of 1-2% per year, which is significantly higher than any other natural ecosystem (Spalding et al., 2010; Giri et al., 2011; Van Bochove et al., 2014; Thomas et al., 2017; Goldberg et al., 2020). Causes of mangrove loss and degradation have been associated with over-harvesting of wood products, conversion of mangrove areas for other land uses such as pond aquaculture, plantation agriculture and infrastructure development; pollution effects, and climate change (Spalding et al., 2010; Giri et al., 2011; Van Bochove et al., 2014). Over the 1985–2010 period, Kenya experienced a 20% reduction in mangrove cover; with disproportionately higher losses reported in urban centres than in rural areas (Kirui et al., 2013).

Demand on forest wood products is directly proportional to human population increase globally. Kenya human population is heavily dependent on wood fuel energy and as a result the country is wood deficient with an annual supply capacity of 31.4 million m^3 against a demand of 41.7 million m^3 (Githiomi & Oduor, 2012; Ministry of Environment and Natural Resources, 2016). A gradually increasing deficit is indicated by 20- year period forecasts which report a 20.0% increase in supply and 21.6% increase in demand by the year 2032 (Githiomi & Oduor, 2012; Ministry of Environment and Natural Resources, 2016). This shows uncertainty in wood supply chain and calls for integrated approaches by all stakeholders including local communities and government agencies (Ototo & Vlosky., 2018).

The management of mangrove forests in Kenya is vested with the Kenya Forest Service (KFS), either alone or in partnerships with the Kenya Wildlife Service (KWS) whenever they occur within marine protected areas (Government of Kenya, 2017) but of late communities living adjacent to the mangrove forests have been incorporated in management through the Participatory Forest Management Programme (PFMP). The service issues annual licenses for commercial harvesting of mangrove wood products. The license stipulates amounts and size classes of poles to be harvested. There is need to understand the dynamism of forest exploitation, supply chain and the role of each actor in mangrove wood market. This study aimed to evaluate sustainability of mangrove harvesting in Lamu County based on the quantity of wood extracted from the forest, harvesting regime and the market demand. Results of this work are vital in the understanding of *winners* and *losers* in the mangrove wood trade.

1.2. Problem statement

Mangroves form about 3% of gazetted forests in Kenya yet they are highly depended upon by coastal communities as a source of their livelihood. Overexploitation of these forests affects the species composition and structural complexity of the forest and hence may impair forest functioning and regeneration. Poor management and the increased wood demand are the key causes of overharvesting and illegal logging of mangroves which eventually contributes greatly to degradation of these forests. There are inconsistencies in the utilization classes of poles removed which may eventually lead to depletion of some size classes since resource use is driven by wood demand rather than the available stock. There’s recognized knowledge gap on valuation studies in Western Indian Ocean region (WIO), Kenya included. A few studies have been done on the economic value of mangrove ecosystem services in Kenya but none has been done on mangrove wood value chain despite the presence of several actors in the market structure of mangrove wood resources. Scant information on mangrove trade puts into question the sustainability of the resource. This lack of information has made mangrove forests vulnerable to overharvesting since it's the market demand for wood that dictates supply from the forest to meet the large wood deficit. At the same time, poor management, unpredictable trends in harvesting of mangroves, unclear market trends as well as limited information on multiple mangrove users makes it difficult for the government to quantify the relative contribution of mangroves on the blue economy. There is need to understand how demand for wood in the market influences removal of poles from the forest as well as the impact it has on the forest. It is necessary to study mangrove wood value chain and how well it could be managed for community development and environmental sustainability.

1.3. General objective

To study the value chain and sustainability of mangrove wood harvesting in Lamu County, Kenya

1.3.1. Specific objectives

i. To determine the merchantable stock of mangroves in Lamu County.

ii. To compare allowable harvest and actual harvest data hence relate to the standing stock of mangroves in Lamu County

iii. To evaluate the market structure of mangroves wood products and hence the value chain of the mangroves of Lamu County.

1.3.2. Research Questions

i. What is the merchantable stock of mangrove forests of Lamu county?

ii. Is there variation between the allowable and actual harvest in relation to the forest standing stock of the mangroves of Lamu County?

iii. What is the market structure of mangrove wood products and value chain of the mangroves of Lamu County?

1.4. Justification

Assessment of forest conditions allows construction of local stand table depicting stocking rates of different size classes against the allowable cut and the harvest data. The status of the forest will inform on its potential for exploitation without getting degraded in the future. Despite the long history of mangrove harvesting and trade, there is scant information on the multiple actors involved and who gains the most in the value chain. There is need to understand the dynamics of forest exploitation and the role played by the actors involved. This will help in improving management and conservation of this critical ecosystem for continued sustainable exploitation.

CHAPTER TWO

LITERATURE REVIEW

2.1. Biogeography of Mangroves

Mangroves are woody shrubs that grow along the tropical and subtropical coastlines (Tomlinson, 2016). They dominate the intertidal zone with a latitudinal extent of 25° N and 25° S with a few exceptions (Kauffman et al., 2012; Lee et al., 2014; Mukherjee et al., 2014; Spalding et al., 2010). This blue carbon ecosystem (Macleod et al., 2011, Nellerman et al., 2009), provide valuable goods and services that are of environmental, ecological and economic importance to human society around the world. These forests grow in harsh environmental settings (FAO, 2010; Giri et al., 2011) hence have developed different morphological and physiological adaptations such as breathing roots and salt secretion (Polidoro et al., 2010).

Globally, mangroves cover an area of approximately 15.6 million hectares accounting for 0.7% of total tropical forests of the world (FAO, 2010). The largest cover of mangroves is found in Asia (42%) followed by Africa (20%), North and Central America (15%), Oceania (12%) and South America (11%) (Giri et al., 2011). However, the status of mangroves is less than half of what it used to be and much of what remains is in a degraded condition (Ward et al., 2016). In Africa, mangroves cover over 3.2 million ha along West Africa and East Africa region (UNEP WCMC, 2006) while mangroves of WIO region have been estimated at 1.0 million ha (Ajonina et al., 2008). Ten mangrove tree species are found in WIO region; *Avicennia marina*, *Rhizophora mucronata*, *Ceriops tagal*, *Lumnitzera racemosa*, *Brugueria gymnorrhiza*, *Sonneratia alba*, *Xylocarpus granatum*, *Xylocarpus mollucensis*, *Heritiera littoralis* and the rare *Pemphis acidula*. In Kenya mangroves cover about 61,000 ha, of which the most extensive forests are in Lamu County covering about 37,350 ha (Government of Kenya, 2017). These forests are dominated by mixed stands of *Rhizophora mucronata* that accounts for 8,649 ha (approximately 23%) of the total forest formation. Other important forest formations in the county are pure stands of *Avicennia marina,* occurring more on the landward side with freshwater inflows as well as stands of *Ceriops tagal* in the mid-zone of the forest (Government of Kenya, 2017; Osuka et al., 2016).

2.2. Mangroves forest structure and floristic composition

Nine of the ten mangrove species recorded in the WIO region are found in Kenya and display horizontal zonation with *Rhizophora mucronata* and *Ceriops tagal* being the most dominant species. The mangroves have a discontinuous distribution along the coastline with the largest coverage of mangrove forests occurring in Lamu county (61%) followed by Kwale, Kilifi, Tana River and Mombasa counties (Kairo et al., 2001; Government of Kenya., 2017).

Overexploitation of mangrove forests affects the species composition and structural complexity of the forest and hence may impair forest functioning and regeneration. Deforestation and overexploitation of mangrove forest influences assemblage of mangrove flora and fauna as reported in several studies in Kenya and elsewhere (Abuodha & Kairo, 2001; Dahdouh-Guebas et al., 2004; Skilleter & Warren, 2000). Overexploited forests are commonly associated with stunted and low forest cover which is reported in Pacific Island of Kosrae (Allen et al., 2001), and in Kenya by Kairo et al., 2002 and Dahdouh-Guebas et al., 2000. Degradation influences forest functioning through decline in primary productivity (Kihia et al., 2010) and herbivory (Kihia et al., 2011). Human physical disturbance also reduces the prevalence of commercially valuable species such as *Rhizophora mucronata* and *Brugueria gymnorrhiza* and eventually leads to their replacement by less valuable species, such as *Avicennia* and *Ceriops* at disturbed sites. Species composition and structural attributes such as stem density, height, basal area, biomass and carbon stocks varies significantly, with reduced values being noted in exploited areas (Dina et al., 2020).

2.3. Mangrove goods and services

Mangroves form one of the most productive and unique ecosystems (Macleod et al., 2011, Nellerman et al., 2009), providing a wide range of goods and services that are of environmental, ecological and economic importance to human society around the world (Costanza, 2008; Spalding et al., 2010). Ecosystem services refer to the benefits people obtain from ecosystems (TEEB., 2010; MEA, 2005). Using the broad Millennium Ecosystem Assessment (2015) categories, mangroves offer provisioning, regulating, cultural and supporting services from their direct, indirect or potential use (MEA, 2015).

Provisioning services: These are products or goods obtained from ecosystems directly. Mangroves provide a variety of wood and non-wood forest products that are used by coastal communities (Duke et al., 2014). Wood products include: building poles, timber, firewood and charcoal that is used in urban and rural areas (Government of Kenya, 2017). Non-wood products derived from mangroves include fish, crabs, shrimps, dyes, tannins as well as traditional medicine.

Regulating services: Benefits obtained from regulation of ecosystem processes/buffering capacity of ecosystem services. In the context of climate change mitigation, mangroves capture and stores carbon in both above and below ground compartments and as sediment organic carbon (Carandang et al., 2013, Donato et al., 2011, Hamilton & Fries, 2018). Mangroves sequester higher amounts of carbon (3 to 4 times) than the terrestrial forests (IUCN, 2018), hence playing a key role in reducing levels of greenhouse gases in the atmosphere (Lee et al., 2014). The contribution of mangrove ecosystems as carbon sinks is crucial in achieving the global sustainable goals as well as the Paris agreement. In their natural environment, mangroves help in attenuating wave energy, stabilizing sediments and hence prevent shoreline erosion (Constanza et al., 2014).

Supporting services: Are services necessary for the production and delivery of other ecosystem services. These include biodiversity conservation, primary production and soil formation. Globally, mangroves provide habitat and refuge for juvenile fish, Plants as well as breeding grounds for many fauna species which include mollusks, crustaceans, reptiles, mammals and birds (Salem & Mercer, 2012a; Spalding et al., 2010; Vegh et al., 2014; Kairo et al., 2008; FAO, 2010).

Cultural services: These are non-material and enriching benefits. For instance, they provide opportunities for ecotourism, recreation, aesthetic value and form spiritual sites. In mangrove areas which are used as shrines, harvesting of trees is highly forbidden therefore maintaining the pristine condition of the forest (Huxham et al., 2018). In addition, mangrove ecosystem also supports research activities and environmental education hence promoting nature studies to students worldwide.

2.4. Valuation of mangrove goods and services

Ecosystem valuation is an economic process which assigns a value (either monetary or biophysical) to an ecosystem and/or biodiversity (MEA, 2005; Constanza et al., 2014). Valuation plays an important role in making informed decisions in real world context for ecosystem conservation (Daily et al., 2009). Ecological economic valuation is an effort to allocate quantitative values to the goods and services provided by natural ecosystems to illustrate the benefits of the extractable products that can be commercialized (Tuan (2013; Rosales et al., 2017; Brander et al., 2010).

Economic valuation studies follow different methodologies (De Groot et al., 2002; TEEB, 2010). In economic valuation, total economic value (TEV) framework is applied and is defined as the sum of the values of all service flows that natural capital generates both now and, in the future, appropriately discounted (TEEB, 2014). The theoretical concept of TEV of mangrove forests contains both the use and non-use values. Use values can be derived from the direct uses such as harvesting poles, fish and collecting fuelwood or indirect uses like flood control and storm prevention. Non-use values include biodiversity, cultural heritage and bequest values (Gilman et al., 2008; MEA, 2015). Economic valuation studies of mangrove ecosystems have been conducted globally in the last few decades. However, most of these studies exist only for mangroves in Asia due to the drastic loss of mangroves in the region (Spalding et al., 2014). Although Africa is home to 20% of world's mangroves, only a few valuation studies have been completed (Kairo et al., 2009) and the overall value of mangroves in WIO region has been estimated at US$ 42.7 billion (Obura et al., 2017). Mangrove services do not have assigned "market prices", thus the value of this unique ecosystem is generally underestimated (Huxham et al., 2015). This can be due to lack of understanding of their ecological and socio-economic values, which results to distorted policy and decision making regarding their use and management (Mukherjee et al., 2014). Several studies have pointed out that economic valuation plays a significant role towards justifying conservation, economic development planning, as well as influencing public policy at a local or national level (Bateman et al., 2015; Guerrya et al., 2015).

In Kenya, there is hardly any study that has traced the economic contribution of mangrove wood products which have assigned “market prices”. In this light, part of this study evaluated the mangrove wood value chain hence providing information on the integrity of Lamu mangrove forest and capacity for sustainable utilization.

2.4.1. Economic valuation techniques

According to TEEB (2010), economic valuation methods are categorized into four types; market valuation, revealed preference, stated preference and benefit transfer. These methods differ in terms of their reliability, validity and applicability. A researcher must decide the suitable method for a study considering the limitations, local circumstances and environmental settings (De Groot et al., 2006). Direct market valuation is applied to services which have market price while indirect market valuation applies to those services which have no assigned market prices.

Market valuation approach follows several methods which include: (i) Market price (market price of the good e.g. timber and fish), (ii) Avoided costs (costs that are avoided through the existence of service e.g. shoreline protection), (iii) Replacement costs (costs of establishing a construct that provides a similar service e.g. water quality improvement), (iv) Production function (contribution of the ecosystem service to the delivery of another marketable good or service e.g. nursery habitat) and (v) Restoration costs (costs of mitigating the effects of lost ecosystem function e.g. flood control) (TEEB., 2010; De Groot et al., 2006).

This study concentrated on direct market valuation technique (market price method) which is the best to apply for direct services such as wood products since they are assigned “market prices” (Kairo et al., 2009). The market price method estimates the economic value of ecosystem products or services that are bought and sold in the markets (Mojiol et al., 2016; Splash, 2007) and can be used to assess value changes in quantity or quality of a good or service (Adeyemi et al., 2012; Borinelli & Rocha, 2006).

2.5. History of mangrove exploitation in Lamu County

Harvesting of mangrove poles for commercial purposes is a major economic activity in Lamu county. The harvested mangrove wood products are locally utilized in Lamu or exported to urban centres for building and construction (Government of Kenya, 2017;

Hamza et al., 2020). For centuries, mangrove poles were an important commercial commodity between East Africa and treeless Arab countries (Rawlins, 1957; Curtin, 1983; Idha, 1998; Omar et al., 2009). By the beginning of the 20th century, Kenya was exporting 24,150 scores from Lamu mangroves, translating to 483,000 poles per year (Grant, 1938) (1 score = 20 poles). Between 1941 and 1956 this export averaged 35,451.3 scores, then dropped to 13,774.4 scores between 1991 and 1996. The major species that were overexploited were *Rhizophora mucronata* and *Ceriops tagal* leading to a great decline in the stand stock in Lamu mangroves. These two species are most preferred since they give best quality timber for construction of houses and are readily available and easily accessible in the forest as compared to other species (Kairo, 2001; Osuka et al., 2016). Charcoal burning is illegal but fuelwood is collected for subsistence use only. Mangrove poles are also used as boat masts and constructing fish traps (Atheull et al., 2009). The poles used in construction are graded into different utilization classes depending on their uses (Kirui, 2013). Larger logs of mangroves especially of *Avicennia marina* are used in traditional boat construction. Aerial roots of *Sonneratia alba* are also used as floaters for fishing nets. Local communities utilize mangrove wood for furniture construction which earns them a lot of income. Among non-timber products obtained from mangrove forests include honey, medicinal extracts, fish and crabs, tannins, dyes and salts (Lang'at et al., 2014).

The highest benefits derived from mangrove forests by the local community in Lamu county include use of the wood for building and fuelwood (Table 2.2). Due to the escalating deforestation trend, a presidential ban was imposed on the foreign export of mangrove poles in 1982 followed by a national ban in 1997 (Omar et al., 2009; Government of Kenya, 2017). Despite the ban, the actual average harvest per year from Lamu for subsistence use remained more or less equal to the 31,734 scores of mangrove poles harvested up to 1983 (FDK, 1983). In 1992, the then Forest Department licensed removal of 72,100 scores yr^{-1} from Lamu forests for domestic use (KFS, 2001).

The major challenges facing sustainable management of mangroves in Kenya include overexploitation of wood products (Government of Kenya, 2017), low community involvement in management, the poverty status of many indigenous coastal communities (Kairo, et al., 2002), limited budget allocation directed to mangrove resources management, and poor governance (Kairu et al., 2018). These challenges persist even with the development of a national mangrove management plan (Government of Kenya, 2017). Unpredictable trends in harvesting of mangroves, unclear market trends as well as limited information on multiple actors hinder sustainable utilization of mangrove resources hence leading to numerous economic losses and degradation of the forest

Table 2.1: Mangrove utilization classes and uses

Utilization classes	Butt diameter (cm)	Uses
Fito	2.5-3.9	Used to fill walls of the traditional houses
Pau	4.0-7.9	They are used for roofing
Mazio	8.0-11.4	Used as roof frames
Boriti	11.5-13.9	main frame of the house walls is made of boriti
Nguzo 1/vigingi	14.0-16.9	used mostly for fencing and covering pit latrines
Nguzo 2	17.0-20.4	Used for fencing, supporting main roof of larger tourist hotels and covering pit latrines
Nguzo 3	20.5-30.4	Used to support main roof of larger tourist hotels and covering pit latrines
Banaa	≥30.5	Not harvested

Source: Adapted and modified from (Government of Kenya., 2017; Kirui., 2013)

2.6. Marketing of mangrove wood products

Trade in mangrove resources involves several actors who play different roles along the value chain (Curtin, 1983). The actors include; KFS, licensees, harvesters, stockists, transporters and sellers (Rosales et al., 2017; Njie, 2011). The licensees buy poles from the harvesters hence acts as middlemen to link the harvesters to the market. Stockists buy mangrove poles from the licensees and they store them in their yards for sale to the final consumers.

At the market, pricing of the mangrove wood products is done depending on the quality and size. Poles in quality class 1 and 2 are viable for the market but those in class 1 are the most merchantable. Poles in quality class 3 are non-merchantable. *Boriti* and *mazio* sells more since they are mostly preferred for construction (Kairo et al., 2002). *Boriti* are the most expensive while *mazio* sells at half the price of *boriti* (Curtin, 1983). The profits acquired at the different stages of the mangrove wood value chain vary greatly since the actors incur different expenses at each stage. Demand for the mangrove wood in the market directly influences supply from the forest. The pressure of exploitation in the forest tends to increase when demand is high. At times the cutters may be tempted to overharvest so as to maintain the supply thus degrading the resource in the forest.

Figure 2.1: (A) Mangrove poles being loaded into a Lorry at the landing site for transportation (B) Offloading of poles from a Jahazi (wooden dug out vessel) at the landing site.

Figure 2.2: Mangrove poles stacked in a yard ready for sale.

2.7. Economic benefits of mangrove exploitation

Mangroves provide direct and indirect goods and services of economic importance to coastal communities. Direct goods include products such as poles, fuelwood, honey, fish and services like flood control, shoreline protection, ecotourism and recreation, education and research, and aesthetic value (Kairo et al., 2002, 2008; Owuor et al., 2019; Huxham et al., 2015). Mangrove poles have been a traditional trading item from East Africa for many centuries (Omar et al., 2009, Idha, 1998). The wood is used for building and heating (Kairo, 2001, Okello et al., 2013). *Rhizophora* species is often preferred for fuelwood and charcoal because it produces little smoke, burns for long and its wood has high calorific value (Gallup et al., 2020).

Apart from using mangroves for their durable poles, tannins are extracted from some species of the mangrove trees with some of the chemical extracts used in folkloric medicine as insecticides and pesticides (Ronnback et al., 2007; Warui, 2011, Kumar et al., 2012). Globally, mangrove ecosystems support and maintain diverse fish species which are highly depended upon by the economies of many countries (Spalding et al., 2010; Vegh et al., 2014; Kairo et al., 2008). Other fauna of economic importance supported by mangrove environments include mollusks, crustaceans, reptiles, mammals and birds (FAO, 2010).

2.8. Threats to mangroves in Kenya

Mangrove forests in Kenya are threatened by both anthropogenic and natural factors. Anthropogenic drivers of mangrove degradation include illegal logging, overexploitation, pollution, shrimp farming, agriculture, coastal developments such as port construction, urban growth and road construction adjacent to highly populated areas. About 80% of the coastal communities derive their livelihood from mangrove ecosystems (Huxham et al., 2018). Natural drivers include climate change events such floods, coastal erosion, storms, cyclones, sea-level rise. Although mangroves in Kenya do not seem to suffer a great deal from natural causes, a few cases have occurred, where mangroves died due to massive sedimentation caused by extreme events (Kairo et al., 2008). During the 1997 and 1998 El Niño phenomenon, massive sedimentation and prolonged water stagnation triggered by abnormally heavy rains caused widespread mangrove die-backs in Lamu, Tana River, Mombasa and Gazi Bay in Kwale County (Dahdouh-Guebas et al., 2005; Government of Kenya, 2017). The rapid increase in population in the coastal areas is a great risk to the mangroves, mostly in areas where government policymakers pay little attention to protect them (Mukherjee et al., 2014; Sarmin et al., 2018). Nationally, there is increasing demand for wood, mostly in the urban areas, both for fuel consumption, charcoal production and timber for building (UNEP, 2011). In Kenya, 70% of domestic energy supply is met by wood fuel (Wafula, 2005), yet there is a deficit of more than 14 million tons. According to (Githiomi & Oduor, 2012; Ministry of Environment and Natural Resources, 2016), Kenya's wood supply capacity is 31.4 million m^3 against a national demand of 41.7 million m^3, hence a deficit of 10.3 million m^3. This remains a great challenge in conservation of forests since supply has to be increased to meet this demand (Ototo & Vlosky, 2018).

Globally, causes of deterioration of mangrove forests include illegal logging, over exploitation for wood products, conversion to alternative land uses, climate change and pollution. About 2% of southeast Asia's mangroves, translating to over 100,000 ha were deforested between 2000 and 2012 due to global demand for commodities with major causes being conversion for shrimp aquaculture and agriculture (Richard & Friess, 2016). In Kenya, overexploitation of mangrove forests for building poles remains the greatest threat. In addition, inadequate knowledge about mangrove importance have hindered efficient management, including participation by local communities towards restoration of degraded areas (Kairo et al., 2002; Huxham et al., 2015). The continued loss of mangroves around the world has threatened many species and negatively impacted close to 100 million people who depend on the coastal resources (UNEP, 2011). Illegal harvesting of mangroves is the main threat facing mangroves of Lamu county. It is common in Pate and Manda Islands where cutting of mangrove wood for making traditional lime resulted to huge bare mangrove areas which may take long to recover naturally (Government of Kenya, 2017).

Table 2.2: Ranking of benefits and threats of mangroves in Lamu County.

Rank	Benefits	Threats
1	Construction poles	Illegal harvesting
2	Fuelwood	Pollution (oil spills)
3	Fish production	Overexploitation
4	Coastal protection	Coastal development
5	Beekeeping	Sedimentation

Source: Government of Kenya (2017)

2.9. Theoretical framework

Value chain is the range of activities required to bring a product or service from production to final consumption (Tuan, 2013; Lowitt et al., 2015). It shows how the values attached to each part of the chain are distributed (Zafar & Ahsan, 2006; Sathirathai, 1998; Thyresson et al., 2013), hence helps in understanding the relationships and interactions amongst actors in a chain as well as considering the potential implications for development (Borinelli & Rocha, 2006; Graef, 2014). Resource value chains are driven by the market forces of demand and supply which directly determines the benefits acquired by the stakeholders involved (Liquete et al., 2013; Ototo & Vlosky., 2018;

Sarmin et al., 2018; Owuor et al., 2019). Value chain analysis (VCA) includes a range of activities from production of the material, and the role of the actors or companies in the negotiation, processing, stocking, transportation, and commercialization until the produce reach the consumer (Brander et al., 2010; Tuan, 2013; Rosales et al., 2017). This form of analysis systematically maps the economic agents involved in the production, distribution, and sales of a particular product, assessing the characteristics of economic agents, profits and costs, goods flow throughout the chain, the destination, and sales volumes (Njie, 2011; Rosales et al., 2017). Sustainable resource exploitation calls for the understanding of various stages of the chain as well as the interactions between the actors. For mangroves VCA, only extractable products are considered (poles, fuel wood and fisheries) (Tuan, 2013, Vegh et al., 2014), and involves multiple actors who play different roles along the value chain. In this study, only mangrove pole value chain was mapped since poles are the only wood products that could easily be tracked from mangroves of Lamu (Kairo et al., 2009; Hamza et al., 2020).

The actors in mangrove wood value chain include: KFS, licensee, cutters, transporters, stockist, and final consumer (Njie, 2011; Rosales et al., 2017). The licensees are the primary actors since they buy from the cutters and sell to the secondary buyers (pole stockists) in various urban centers who in turn sell to the final consumers. Transporters ferry the poles from the cutters to the licensee (mostly by dhows) and also supply the poles from the licensee (mostly by lorries) to the stockists in various urban centres.

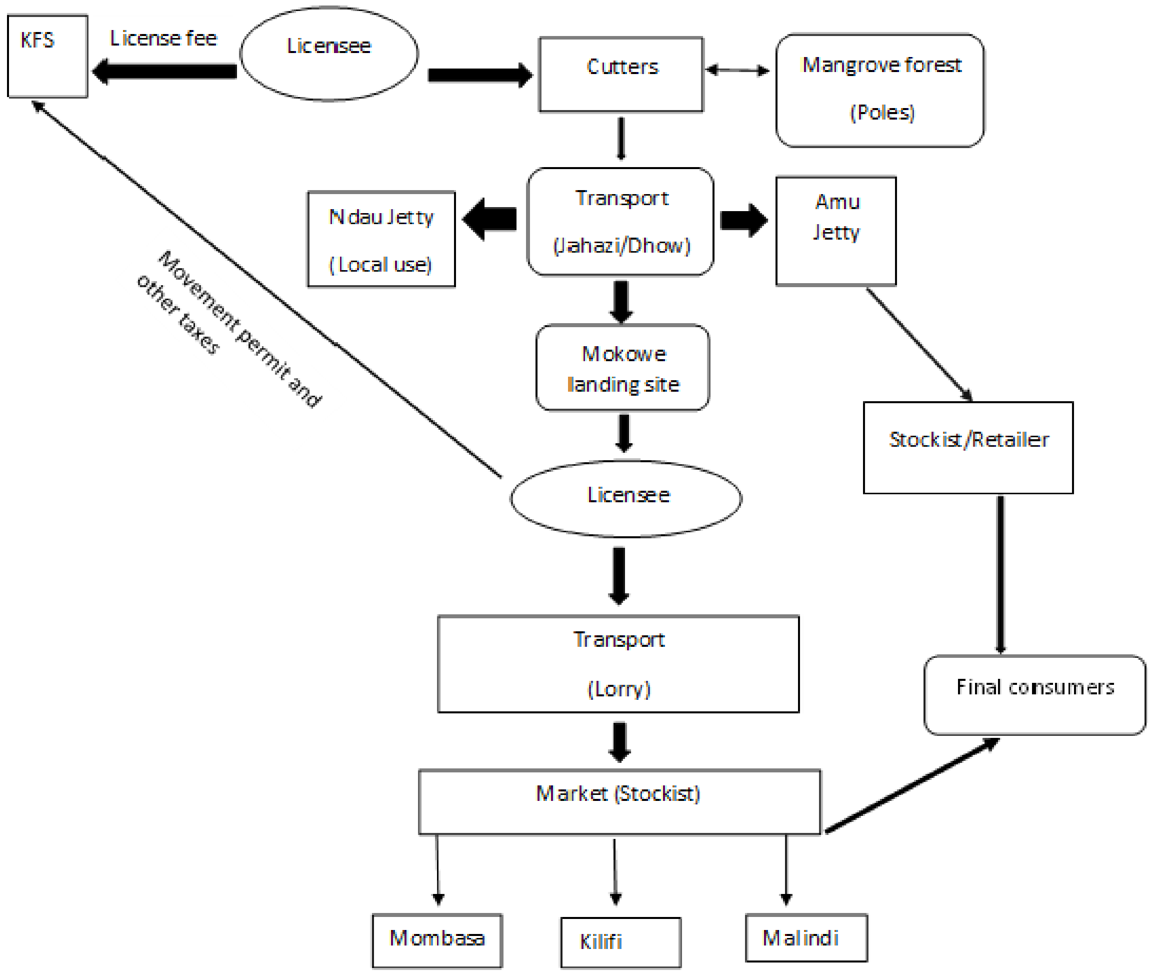

Figure 2.3: Mangrove wood value chain in Lamu, Kenya. Malindi, Kilifi and Mombasa are the main urban centres where mangrove poles are traded.

The licensees register with the KFS by paying a royalty fee of $ 93.17 year^{-1}. The issued license designates harvesting areas, utilization classes and quantity of mangrove poles to be extracted from the forest (Mbuvi et al., 2003; Kairo et al., 2008). Licensees then hire cutters who do the logging. The cutters use dhows to enter the forest where they do selective harvesting using a handsaw and hand axe (Atheull et al., 2009). Through traditional knowledge of the monsoon wind patterns; *Kussi* (Southeast monsoon winds) or *Kaskazi* (Northeast monsoon winds) they can decide the specific areas for harvesting.

Harvested mangrove poles are sorted into different utilization classes based on butt diameter, height, and straightness of the poles as well as the number of nodes in a pole (Kairo, 2002). The most preferred classes are the *boriti* sized poles (11.5-13.9 cm) that are used to construct the main house framework. This is followed by *mazio* (8.9-11.4 cm) and *pau* (4.0-7.9 cm) sized poles (Kairo et al., 2002; Table 2.1)

As part of processing, the bark is removed in *boriti* and *vigingi* sized poles. As for *mazio, pau and fito* poles' the bark is not stripped off. The poles are usually dipped in the sea water before transportation as a way of seasoning them. The cutters bring the poles to the landing site using *Jahazis* (wooden dug out vessels). On average a *Dhow* (or *Mashua*) can transport 150 scores of *boriti* (Kabii, 991). Cutters are paid for the product by licensees at Ndau, Amu or Mokowe jetty, though the prices vary because of additional expenses incurred in the transportation to different destinations. At the landing site, poles are piled in their respective size classes and graded awaiting transportation by lorries or trucks to urban centers (Arton et al., 2017).

At the jetty, KFS officials counts the extracted scores, mark and stamps each pole with a unique code designed for each forest zone. The marking helps the KFS to trace sources and transit of all the poles along the value chain, indicates payment to KFS and to track extracted wood. Charges on movement permit vary depending on tonnage: ≤3 tonnes - $ 9.32, 3.1- 6.9 tonnes - $13.98, ≥7 tonnes - $18.6 per consignment. Licensee transport and distribute the poles to the stockists in different urban centers including Malindi, Watamu, Kilifi, Mombasa and Voi. Licensees sell the poles to stockists at a price almost three times the original price. Stockists pile the poles in their yards and sell at double the buying price (per pole rather than score). Change in demand for the poles directly affects supply hence the profit accrued by each actor as well as the status of the forest.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Study area

This study was carried out in the northern part of Kenyan coast in Lamu county (1.6537°S, 41.5598°E and 2.4776°S, 40.7060°E), which covers an area of about 6,607 km^2. The coastline for this county stretches to about 130 km and is renowned for its rich biodiversity and a unique ecosystem that combines both marine and terrestrial wildlife. The Lamu Archipelago is a significant world ecological and cultural heritage with 75% of Kenya's mangrove forests located here. It is a Ramsar site and has outstanding and endemic marine biodiversity of diverse coral reefs, sea-grass beds, sand bars, lagoons and creeks that support a lucrative fishing industry (Lamu CIDP, 2018; Government of Kenya, 2017).

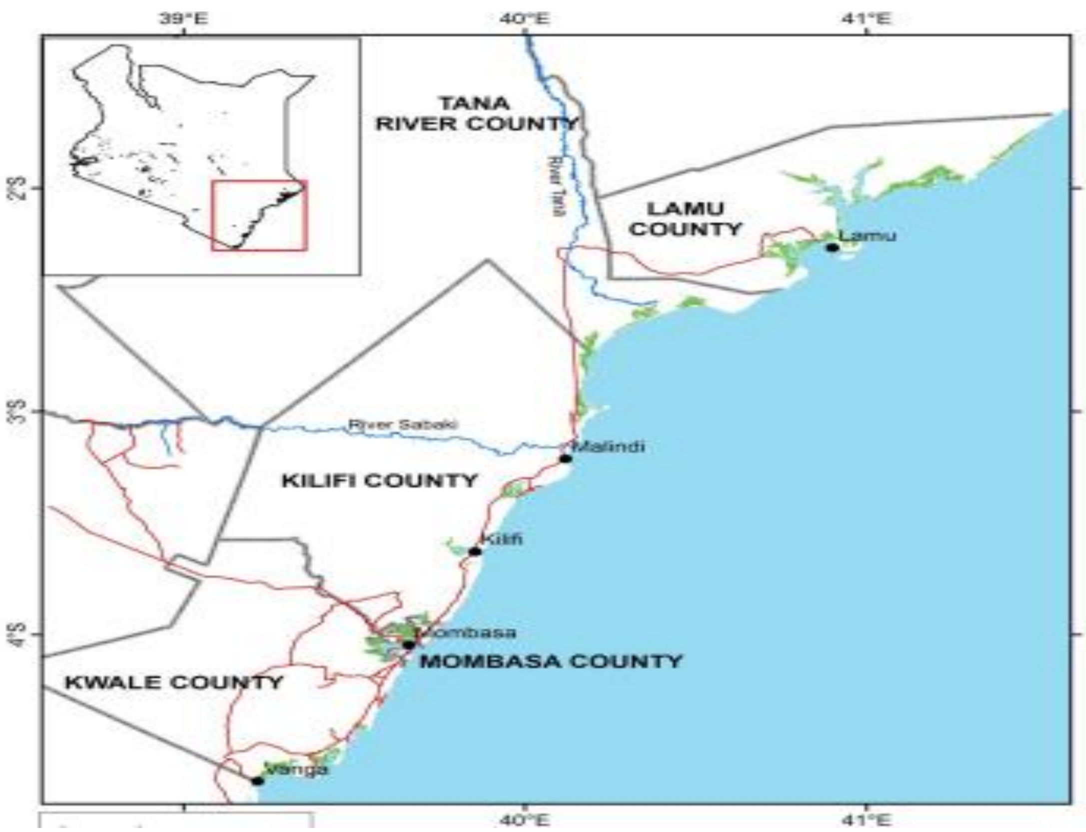

Figure 3.1: Location of Lamu County on the Kenyan coastline. Source: Government of Kenya (2017)

3.1.1. Administrative units

Lamu county has vast hinterlands bordering the seascape with 65 Islands that constitutes the Lamu archipelago. Of the multiple islands, only Lamu, Manda, Pate, Kiwayu, and Ndau are inhabited as the others have challenges of insecurity, inaccessibility, and lack of fresh water (Lamu CIDP, 2018). Administratively, Lamu county is composed of two constituencies namely; Lamu east and Lamu west. The county is made of seven divisions, 23 locations and 39 sub locations. The population stands at 143,920 persons (KNBS, 2019). Faza sub county in Lamu east consists of five locations; Pate, Faza, Kizingitini, Siyu, and Tchundwa. Faza location has two sublocations: Faza and Ndau, the latter covering Ndau, Kiwayu and Chandani villages (KNBS, 2019). Ndau village was chosen as the base for the interviews.

3.1.2. Biophysical and climatic conditions

The county has a generally hot and dry climate with a mean annual temperature above 25°C, and a mean annual rainfall 900 mm yr^{-1}. The rainfall pattern is bimodal, greatly influenced by monsoon winds. Two monsoon seasons occur resulting in the two rainy seasons. Short rains occur from October to December during the Northeast monsoons. The long rain season occur from March to May during the South East monsoons. The central parts of the county receive the highest rainfall totals averaging over 1000 mm per year while the northeastern parts receive between 500 and 1000 mm on average. Some places in the south receive an average annual rainfall of less than 250 mm. The soils are sandy, which contributes to low agricultural productivity (MoALF, 2018). The months of August and September, are usually characterized by cessation of south east trade winds, diminishing rainfall and a gradual change in wind direction. The sea remains rough during this period.

3.1.3. Socio-economic status

Lamu being one of the earliest seaports in East Africa, attracted traders from various parts of the world. The county saw many visitors over its long history including traders and explorers from Portugal, India, China, Turkey and much of the Middle East whose marks are still felt in the area and which contributed to Lamu being recognized as UNESCO world heritage city. Much of Lamu's culture is still conserved with arts playing a crucial role in preserving the rich cultural fabric in form of woodcarving, furniture making, boat building, jewellery, calligraphy and poetry (Lamu CIDP, 2018).

The social economic fabric is in two livelihood classes which include the rich agricultural zones (found in the mainland), and fishing and marine zones (found on the island). Majority of the human population, depend on nature-based livelihoods such as fishing, mangrove cutting, hunting and gathering, pastoralism, farming, eco-tourism traditional maritime activities, traditional wood curving and carpentry. These sectors together employ over 80% of Lamu's total labour force (Lamu CIDP, 2018). The main forest products include the mangrove poles used for construction, fire wood, charcoal, and casuarinas poles. Mangrove poles have been sold for years to the Middle East before the presidential ban on foreign export was placed in 1982 (Government of Kenya, 2017; Omar et al., 2009).

Over 30,000 families depend directly on mangrove harvesting and sale of mangrove products. Trade in mangrove products such as timber, poles, charcoal, firewood and honey are the main economic activities in Lamu (Idha, 1998; Lamu CSP, 2016). Most of the people also engage in fishing and trade in fishery products either on a small scale or large scale. The major impediments to development include high rates of illiteracy and unemployment, poor marketing and storage facilities for fish and agricultural produce, high incidences of agricultural pests, poor infrastructure, low electricity connectivity, insecurity and widespread poverty (MoALF, 2018; Lamu CIDP, 2018). The construction of Lamu Port which is part of the LAPSSET project is a great opportunity for growth of the county’s economy. It will not only promote trade between countries as a terminal for petroleum and crude oil transport but will also promote growth of tourism (Lamu CIDP, 2018).

3.2. Mangroves of Lamu County

The mangrove forests cover in Lamu County is estimated at 37,350 ha, representing 62% of the mangrove coverage in Kenya (Government of Kenya, 2017). All the nine mangroves’ species found in Kenya occur in the county. The dominant species are *Rhizophora mucronata* (or ‘*Mkoko*’ in Swahili language) and *Ceriops tagal* (*Mkandaa*) that constitutes more than 73% of the forest formation (Government of Kenya, 2017). The other species are *Sonneratia alba* (*Mlilana*), *Brugueria gymnorrhiza* (*Muia*), *Avicennia marina* (*Mchu*), *Xylocarpus granatum* (*Mkomafi*), *Xylocarpus moluccensis* (*Mkomafi dume*), *Lumnitzera racemosa* (*Kikandaa*), and *Heritiera littoralis* (*Mkungu*) (Table 3.1).

Table 3.1: Mangrove Forest formation in Lamu County

Classification	Area (ha)	% Cover
Avicennia marina	6,966	18.7
Avicennia mixed with *Ceriops*	1,961	5.3
Ceriops tagal	5,155	13.8
Ceriops mixed with *Brugueria, Rhizophora and Avicennia*	1,901	5.1
Ceriops-Rhizophora	5,138	13.6
Rhizophora mucronata	5,558	14.9
Rhizophora mixed with *Ceriops, Brugueria, Avicennia*	8,649	23.2
Sonneratia alba	1,165	3.1
Sonneratia-Rhizophora	856	2.3
Total Mangrove cover	**37,350**	**100**

Source: Government of Kenya (2017)

Historically, mangroves in Lamu have provided wood and non-wood products to the people (Kairo et al., 2008; Hamza, 2020; Kairo et al., 2021). This is in addition to the value of mangroves in shoreline protection and biodiversity conservation (Kairo et al., 2008; Kirui, 2013; Kairo et al 2021). According to the National Mangrove Ecosystem Management Plan (Government of Kenya, 2017), mangroves in Lamu have been classified into five management blocks. Each of these blocks is clearly separated from the other by natural features such as channels, islands, and creeks. The Northern swamps extend from Mlango wa Chano to Kiunga; and is dominated by pure stands of *Rhizophora mucronata*. North central swamps extend from Mlango wa Chano to the mouth of Dodori creek. They include mangroves of Uvondo and Ndau islands. Northern central forests are highly stocked with *Ceriops tagal* and *R. mucronata* stands. Mongoni and Dodori creek swamps comprises the mangroves found in Mongoni, Dodori creek and Manda Bay, and are stocked with pure stands of *C. tagal*. Pate island swamps includes the mangroves surrounding Pate Island, Shindabwe, Kizingitini and Chongoni. Southern swamps are the largest of the five management blocks; and include mangroves of Mkunumbi and Kimbo creeks (Fig 3.1). Mangroves in Northern swamps and in some parts of the Northern central swamps are within the Kiunga Marine National Reserve (KMNR). For purposes of this study, the same management boundaries were adopted for ease of reference and comparisons.

KFS controls harvesting of mangroves through issuance of harvesting license (Government of Kenya, 2017). However, the permits issued are often based on the wood demand rather than the available stocks (Kairo et al., 2002). This procedure has contributed to near depletion of the market sized poles in Northern central swamps where commercial harvesting is extensive (Kairo et al., 2021; Okello et al., 2022).

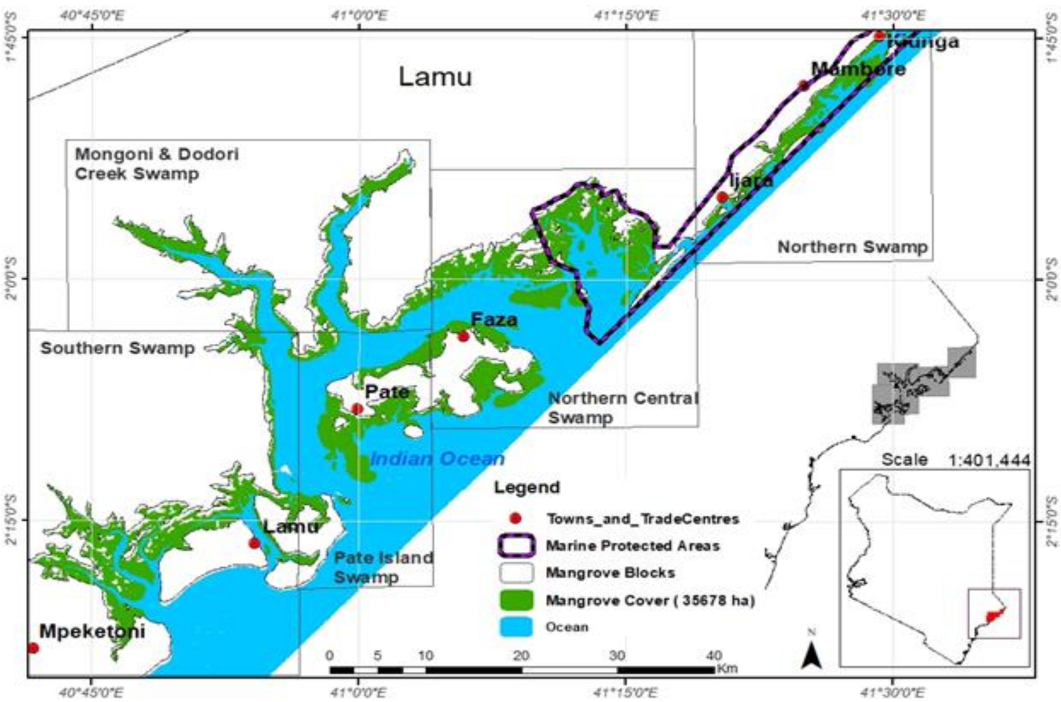

Figure 3.2: Map of mangrove forests cover of Lamu County. Source: Government of Kenya (2017)

3.3. Data collection

3.3.1. Yield data of Lamu mangroves

Stratified random sampling design based on the mangrove forest type was used for vegetation surveys. Stock level data was collected within square quadrats of 20 m by 20 m established along belt transects perpendicular to the waterline. The 400 m^2 square plots for vegetation sampling were preferred in order to take care of the larger tree diameters and avoid overestimation of forest structure. All assessments were conducted consistently across the five blocks and data collection done during the spring tides. Within each plot, trees species were identified, measured and their position marked. The attributes determined included: tree height (m), stem diameter taken at 130 cm breast height (DBH, cm), and cover (%). Stem diameter was measured at 130 cm above the ground level (Brokaw & Thompson, 2000; Cintron & Novelli, 1984). In the case of *R. mucronata*, a structurally complex species, (Dahdouh-Guebas & Koedam, 2006), stem diameter was taken 30 cm above the highest prop root (Komiyama et al., 2005). Tree heights were measured using a hypsometer while the stem diameter was measured using a forester's caliper. In case of a stem forking below 130 cm, individual 'branches' in a clump were treated as separate stems. This data was used to derive local stand tables (m^2 ha^{-1}) and stand density (number ha^{-1}). The basal area (Ba, m^2 ha^{-1}) and stand density (stems ha^{-1}), for each tree species were derived using methods described by (Cintron & Schaeffer-Novelli, 1984; Dahdouh-Guebas & Koedam, 2006).

Stems of mature trees were further categorized into utilization classes with different sizes for recording purpose according to Kairo et al. (2001). In order to assess the quality of forest stand, all trees with stem diameter > 5.0 cm within sampling plots were assigned into quality classes (Form) depending on their suitability for construction. Quality Class (QC) 1 trees were straight poles most suitable for constructions, QC 2 trees for intermediate quality poles which can be modified and used for construction, while QC 3 are trees with generally crooked poles, not suitable for building (Kairo, 2001; Kairu et al., 2021).

3.3.2. Basal area and stem density

The basal area (BA) of each species was calculated as the sum of the cross-sectional areas (CSA) of all trees of the species (m^2 ha^{-1}) at breast height (Equation (1), below). Stem density (a measure of abundance) was calculated as the sum of the number of stems per plot, divided by the area of the plot in m^2 multiplied by 10,000 (Equation (2), below).

$$BA\ (m^2\ ha^{-1}) = \text{Sum of cross-sectional area /plot area } (m^2) \times 10{,}000 \qquad \textbf{Eqn. 1}$$

$$\text{Stem density (Stems } ha^{-1}) = \text{No. of stems in plot /plot area } (m^2) \times 10{,}000 \qquad \textbf{Eqn. 2}$$

3.3.3. Importance Value and Complexity Index

The ecological importance value index of each species (IV) (a measure that indicates the relative contribution of a plant species to the structure of a stand) was calculated by summing its relative density, relative frequency and relative dominance (Cintron & Schaeffer-Novelli, 1984) (Equation (3), below). The relative equations are given in Equation 6, 7 and 8 below. The complexity indices (C.I) of each forest zone, (a measure of how complex or structurally developed a vegetation stand was computed as the product of number of species, basal area (BA) ($m^2\ ha^{-1}$), mean tree height (m) and stem density (D, ha^{-1}) × 10^{-5} (Equation (4) below).

$$\text{Importance value (IV)} = \text{Relative density} + \text{relative frequency} + \text{relative dominance} \qquad \textbf{Eqn. 3}$$

$$\text{Complexity index (C.I)} = \text{Number of species} \times BA\ (m^2\ ha^{-1}) \times \text{mean. Height (m)} \times \text{density } (ha^{-1}) \times 10^{-5} \qquad \textbf{Eqn. 4}$$

$$\text{Basal Area } (cm^2) = (\pi DBH^2/4) = 0.7854DBH^2\ cm^2 = 0.00007854m^2 \text{ where } \pi = 3.141 \qquad \textbf{Eqn. 5}$$

$$\text{Relative density} = (\text{Number of individuals of a species/total number of individuals}) \times 100 \qquad \textbf{Eqn. 6}$$

$$\text{Relative dominance} = (\text{Total basal area of a species/Basal area of all species}) \times 100 \qquad \textbf{Eqn. 7}$$

$$\text{Relative frequency} = \text{Frequency of a species/sum frequency of all species}) \times 100 \qquad \textbf{Eqn. 8}$$

3.3.4. Impact of exploitation of mangroves in Lamu County

Field visits were done within the forest blocks under harvesting and at the landing sites to establish the relative sizes of mangrove wood products extracted from the forest. Observations made include, most harvested mangrove species and most preferred utilization classes. These observations together with archived forest data from KFS dating 1992-2018 was used to establish harvesting trends so as to deduce the sustainability of the forest exploitation. This was compared against allowable harvest to establish the intensity of harvesting. Data on the current stocking rates of the forest was generated through cruise surveys across all the mangrove management blocks in Lamu.

3.3.5. Determination of mangrove value chain

Purposive sampling was adopted for the collection of the primary data. The value chain actors were identified by snowball sampling. Actors were recruited by referral from one stage of the value chain to the next, based on respondent information about the other actors (Maraseni et al., 2018). This is helpful in triangulating and validating information provided by different actors. Semi-structured interviews were used to document key actors in mangrove trade (ter Mors et al., 2013; Schaafsma et al., 2017, Table 4). Northern central swamps at Ndau were chosen as the base village for interviews as the livelihood of approximately 85% (about 3,000 residents) in the area is derived from mangrove activities. Daniel's (1999) sampling formula, reviewed in Daniel and Cross (2018), was used to determine the sample size of the study:

$$= \frac{N \times X}{X + N - 1}$$

Where, X = Zα/2 *p*(1-p) / MOE2 (Zα/2 is the critical value of the normal distribution at α/2, e.g., when the confidence level for this study is 95 %, α is 0.05 and the critical value is 1.96), MOE is the margin of error, p is the sample proportion (50 % for this study), and N is the population size) (Daniel & Cross, 2018).

Ndau, Amu and Mokowe are islands in Lamu county and it's where most of the actors in the mangrove value chain are based.

Table 3.2: Value chain actors interviewed

Actor	Male	Female	Total number interviewed	Location
KFS officials	4	2	6	Mokowe (5) & Amu (1)
Licensees	5	3	8	Ndau (4) & Amu (4)
Cutters	50	0	50	Ndau
Jahazi transporters	7	0	7	Ndau
Lorry transporters	5	0	5	Mokowe (3),Malindi (1) & Mombasa (1)
Stockists	24	6	30	Malindi (8), Watamu (5), Kilifi (7) & Mombasa (7)

A total of 106 respondents were sampled for the survey (Table 3.2). Data collected during field interviews included: (i) mangrove utilization classes (ii) price per pole (iii) transporting costs and (iv) the levy paid to KFS. Interviews with the KFS officials sought to understand procedures to acquire authorization to cut mangrove trees, amounts allowed to be harvested in a specified area over a certain period, the sizes of trees to be harvested, how much one pays for licensing and how the trade is regulated (see appendices 1 & 2).

3.3.6. Market survey

The informants were identified purposively following visits to the various urban centers (Malindi, Watamu, Kilifi and Mombasa) where mangrove poles are stocked for sale. Only stockists who were in the pole trade for at least 10 years were selected as their information was considered more reliable. The sample size was determined by the availability of the stockists and their willingness to participate in the survey. A total of 30 individual interviews were conducted with pole stockists (Table 3.2). The information sought included prices for the different pole sizes, transport and any other associated costs. The market price method (Spaninks & Beukering, 1997; Brander et al., 2010; Adeyemi et al., 2012) was used to assess the value of mangrove poles which was established through the exchange of goods and services in the market (Splash, 2007; Carson, 2012), and the interaction between the production value (supply) and the consuming value (demand) (Spaninks and van Beukering, 1997; Adeyemi et al., 2012). The existing market prices were used to estimate the costs, revenue, and profits for each actor in the value chain from a typical sale of mangrove poles (Bandeira et al., 2016a; Macamo et al., 2016b). Similar approaches have been used in mangrove valuation studies in other areas (Sathirathai, 1998; Brander et al., 2010; Adeyemi et al., 2012; Bandeira et al., 2016a; Macamo et al., 2016b) and a recent study conducted in central Mozambique (Machava-António et al., 2020). During the interviews, all the costs and returns for the different actors were recorded with the consent of the participant (Maraseni et al. 2018). Profits per unit of final products between the value chain actors were compared. Common units were used for comparison as used in other studies such as Purnomo et al., (2009).

3.4. Data analysis

All statistical analysis was done using R- Statistics (version 3.6.1). Mean differences between the utilization classes were compared using one way ANOVA at probability level $p \leq 0.05$. Stem densities across the 5 blocks were compared using t-test. If a significant difference ($P \leq 0.05$) was encountered, a Tukey HSD test was performed to determine the potential source of difference.

Post hoc test was used for means separation. The net profit for each actor was calculated by subtracting the total costs incurred from the total revenue received. Thus:

$$\text{Profit from wood} = \sum (Pw\ Qw - Cw),$$

where Pw = price of wood (KSh), Qw = quantity of wood (in scores),

Cw = total costs incurred (KSh)

The cost benefit ratio was computed by dividing total cost and production value for each of the actors. The mean differences in profits amongst value chain actors were compared using one-way ANOVA

CHAPTER FOUR

RESULTS

4.1. Stocking rate and yield data of Lamu mangroves

Six mangrove species were encountered both in the adult and juvenile stages, existing in either pure or mixed stands (Table 4.1). *Xylocarpus granatum* was only present in Pate Island and Mongoni-Dodori Creek swamps. *Rhizophora mucronata* and *Ceriops tagal* have the highest stocking density across the 5 blocks (Table 4.1). Mangroves in the southern swamps are the densest (3,092 stems ha^{-1}) while those in Northern swamps have the least stocking density (1,602 stems ha^{-1}) but with second largest basal area (Table 4.1). There was no significant difference in stocking densities between the five blocks ($H=1.7$, $p = 0.06$). Overall Lamu mangroves have a stocking density of 2,370 stems ha^{-1}.

In all the blocks, *Rhizophora mucronata* contributes the most in terms of the structural complexity of the Lamu County mangrove forest followed by *Ceriops tagal* (Table 4.1), except in Pate Island swamps where *Ceriops tagal* has the least contribution (IV= 20.7). Except in Pate Island swamps, *Rhizophora mucronata* and *Ceriops tagal* have the largest basal areas and highest relative values i.e., density, dominance and frequency (Table 4.1).

Out of the five mangrove management blocks, mangroves in the southern swamps are the most structurally complex (Complexity index (CI)= 30.4), followed by those in Northern swamps (CI= 21.8), the Northern central swamps (CI=21.4). Mangroves in Dodori-Mongoni creek swamps are the least complex (CI= 11.1).

Table 4.1: Structural attributes of Lamu County mangroves

Block	Species	Stems ha^{-1}	Mean Height (m)	BA (m^2)	Relative derivatives (%)				
					Density	Dominance	Frequency	IV	CI
Northern central swamps	*A. marina*	78	3.8	2.5	3.2	7.9	6.5	17.5	21.4
	B. gymnorrhiza	48	6.1	1.2	1.9	3.7	14.3	19.9	
	C. tagal	943	4	4.3	38.3	13.6	26	77.9	
	R. mucronata	1299	6.5	19.8	52.8	63.1	45.5	161.3	
	S. alba	92	8.5	3.7	3.7	11.8	7.8	23.4	
	Total	2460	5.5	31.4	100	100	100	300	
Pate Island swamps	*A. marina*	141	7.7	1.2	5.8	7.6	9.7	23.1	16.0
	B. gymnorrhiza	438	4.3	0.6	18.1	3.5	12.9	34.5	
	C. tagal	96	4.2	0.1	4.0	0.6	16.1	20.7	
	R. mucronata	1327	7.0	7.9	54.9	48.2	41.9	145.0	
	S. alba	295	9.0	4.8	12.2	29.4	16.1	57.7	
	X. granatum	121	7.8	1.8	5.0	10.7	3.2	19.0	
	Total/Mean	2420	6.7	16.4	100.0	100.0	100.0	300.0	
Dodori Mongoni creek swamps	*A. marina*	238	4.0	1.3	10.5	10.5	8.3	29.3	11.1
	B. gymnorrhiza	67	5.8	0.3	3.0	2.4	16.7	22.0	
	C. tagal	709	5.9	2.4	31.2	19.3	25.0	75.5	
	R. mucronata	917	6.7	4.3	40.4	34.4	30.6	105.3	
	S. alba	245	8.8	3.2	10.8	25.1	11.1	47.0	
	X. granatum	94	8.3	1.1	4.1	8.4	8.3	20.8	
	Total	2270	6.4	12.6	100.0	100.0	100.0	300.0	
Southern swamps	*A. marina*	128	3.6	1.3	4.2	3.2	7.4	14.8	30.4
	B. gymnorrhiza	141	4.8	2.7	4.6	7.0	20.4	31.9	
	C. tagal	814	3.2	3.9	26.3	10.0	26.9	63.1	
	R. mucronata	1952	5.8	29.4	63.1	75.4	39.8	178.3	
	S. alba	57	7.7	1.7	1.9	4.4	5.6	11.8	
	Total	3092	5.0	39.0	100.0	100.0	100.0	300.0	
Northern swamps	*A. marina*	63	4.8	1.0	3.9	2.9	7.4	14.1	21.8
	B. gymnorrhiza	24	5.9	0.3	1.5	0.8	7.4	9.6	
	C. tagal	238	3.8	1.4	14.8	4.1	19.1	38.0	
	R. mucronata	1109	9.1	26.2	69.0	76.2	52.9	198.2	
	S. alba	174	7.5	5.5	10.8	16.0	13.2	40.1	
	Total	**1607**	**7.9**	**34.3**	**100.0**	**100.0**	**100.0**	**300.0**	

This study established that the stocking rates for principal mangrove species in Lamu county range from 1048 - 2,142 stems ha^{-1} (mean: 1425±191 stems ha^{-1}) for *R. mucronata* and 104– 967 stems ha^{-1} (mean: 605±178 stems ha^{-1}) for *C. tagal* (Table 4.2*)*. These are the most exploited mangrove species for building poles and fuel wood. The merchantable densities of the two species were estimated at 1,361 stems ha^{-1}; represented mainly by *pau* sized poles (554 stems ha^{-1}), followed by *fito* (480 stems ha^{-1}) across the four blocks where harvesting is allowed (Table 4.3). The density of non-merchantable *nguzo 2* stems is higher than the merchantable stems in northern central swamps and southern swamps (Fig 4.2b).

Banaa (≥30.5cm) are not harvested since they are not viable for the market. They are of a huge butt diameter hence not suitable for construction. Northern swamps *(NS*) recorded the highest number of non-merchantable *boriti* stems (Fig 4.2a).

Table 4.2: Comparison of the stem density for the two dominant species

Management block	Species	
	Ceriops tagal	***Rhizophora mucronata***
Dodori & Mongoni creek swamps	811	1048
Pate Island swamps	104	1429
Northern central swamps	967	1333
Northern swamps	251	1171
Southern swamps	893	2142
Mean	**605±178**	**1425±191**

Overall stem density decreases with increase in diameter (Table 4.3). Dodori-Mongoni creek swamps had a higher density of merchantable poles (1,271 stems ha^{-1}; which constituted 68%), followed by northern central swamps, 1,469 stems ha^{-1}. Southern swamps recorded the least proportion of total merchantable stems (1,743 stem ha^{-1} out of 3,035 stems ha^{-1}; constituting 57%) (Table 4.3).

Table 4.3: Yield data of principal mangrove species (Stems ha^{-1}) in Lamu County.

Management Block		Fito	Pau	Mazio	Boriti	Nguzo 1	Nguzo 2	Nguzo 3	Banaa	Total
		2.5-3.9	4.0-7.9	8.0-11.4	11.5-13.9	14.0-16.9	17.0-20.4	20.5-30.4	≥30.5	
Northern swamps	Merchantable	109	320	222	42	41	70	115	19	**939 (66)**
	Non-merchantable	83	199	16	56	67	16	25	21	483 **(34)**
	Total Stems ha^{-1}	**192**	**519**	**238**	**99**	**108**	**86**	**140**	**40**	**1422**
Northern central swamps	Merchantable	516	680	110	47	25	19	52	19	**1469 (64)**
	Non-merchantable	285	312	112	12	26	26	49	10	831 **(36)**
	Total Stems ha^{-1}	**801**	**992**	**221**	**59**	**51**	**46**	**101**	**29**	**2300**
Southern swamps	Merchantable	624	716	178	50	70	30	60	15	**1743 (57)**
	Non-merchantable	340	617	145	40	30	65	44	12	1293 **(43)**
	Total Stems ha^{-1}	**965**	**1333**	**323**	**90**	**99**	**95**	**104**	**27**	**3035**
Pate Island swamps	Merchantable	256	342	85	44	56	87	77	13	**960 (63)**
	Non-merchantable	123	244	87	29	15	17	52	6	573 **(37)**
	Total Stems ha^{-1}	**379**	**587**	**171**	**73**	**71**	**104**	**129**	**19**	**1533**
Dodori & Mongoni creek swamps	Merchantable	523	479	96	45	32	36	41	20	**1271 (68)**
	Non-merchantable	116	295	95	36	16	16	14	0	588 **(32)**
	Total Stems ha^{-1}	**639**	**773**	**191**	**80**	**48**	**52**	**55**	**20**	**1859**

*Values in Parentheses indicate percentage merchantable stems per management block. Second row values represent the stem diameter (cm). Merchantable stems consist quality class 1 &2, non-merchantable stems consist quality class 3.

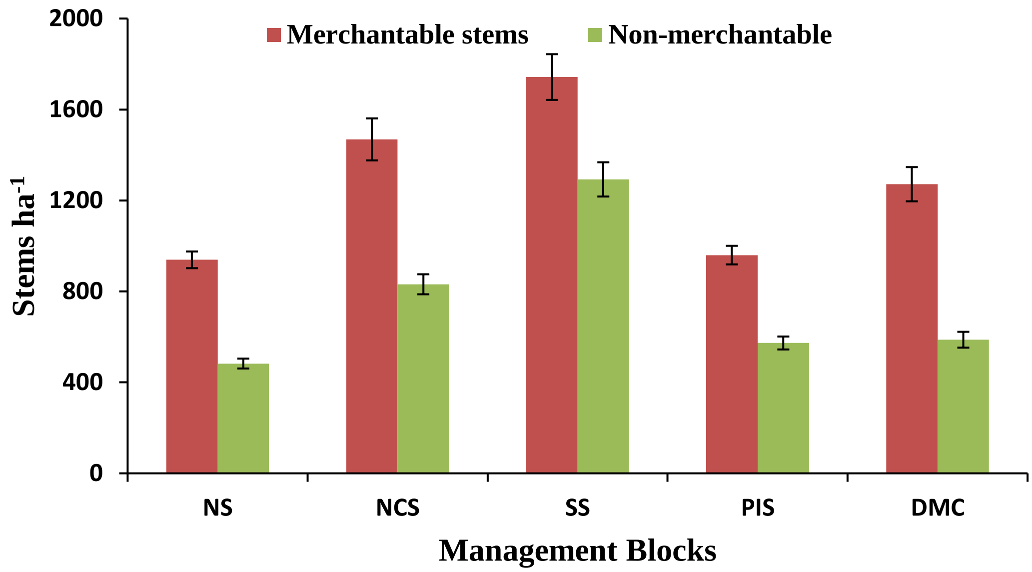

Figure 4.1: Number of merchantable and non-merchantable stems in the five blocks (NS: Northern Swamps, NCS: Northern Central Swamps, SS: Southern Swamps, PIS: Pate Island Swamps and DMC**:** Dodori-Mongoni Creeks).

In all the blocks, the number of merchantable stems was higher than non-merchantable stems (Fig 4.1) except for *mazio* in northern central swamps (NCS) and Pate Islands swamps (PIS) (Table 4.2). With an average stocking density of 43 merchantable stems ha^{-1}, *nguzo 2* (17.0-20.4 cm) sized poles are the least available in all management blocks followed by *nguzo 1* (14.0-16.9 cm) 46 stems ha^{-1} and then *boriti* (11.5-13.9 cm) 47 stems ha^{-1} (Table 4.3).

Table 4.4: Mean number of stems per utilization class in the four blocks where harvesting is allowed (NCS, PIS, SS, DMC)

Utilization classes	Fito	Pau	Mazio	Boriti	Nguzo 1	Nguzo 2	Nguzo 3	Banaa	Total
Merchantable	480	554	117	47	46	43	58	17	1361
Non-merchantable	216	367	110	29	22	31	40	7	822
P value	0.02*	0.08^{ns}	0.38^{ns}	0.03*	0.04*	0.28^{ns}	0.08^{ns}	0.01*	0.03*

* Means statistically significant while ^{ns} means non-statistically significant at $p \leq 0.05$.

Nguzo 1&2 are commonly referred to as '*vigingi*' in the market while *nguzo 3* is referred to as '*nguzo*'. *Boriti* and *nguzo 2* are the most harvested utilization classes.

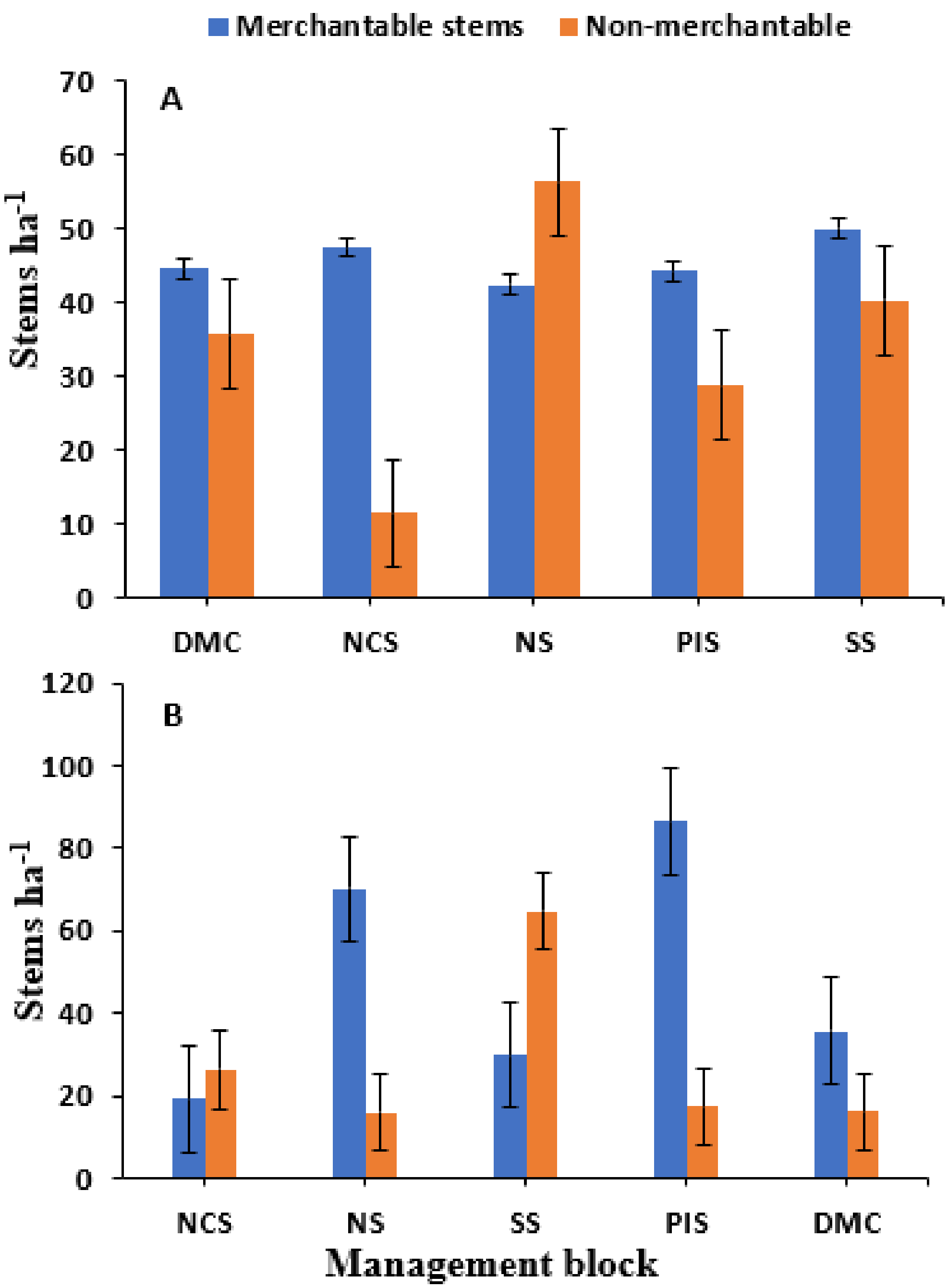

Figure 4.2: (A) Density of merchantable and non-merchantable boriti (B) Density of merchantable and non-merchantable nguzo 2 per block**.**

As appearing in the histograms below (Figs 4.3, 4.4,4.5,4.6 and 4.7), the size classes general distribution for *Ceriops tagal* and *Rhizophora mucronata* in the 5 blocks, shows nearly reversed J- shaped curves which is a common distribution for a natural forest (Kairo et al., 2001). They show that stems density decreases as diameter increases i.e., there is a higher number of *fito* and *pau* (4.0-7.9 cm) trees while the density of trees in the other size classes decreases with increase in DBH.

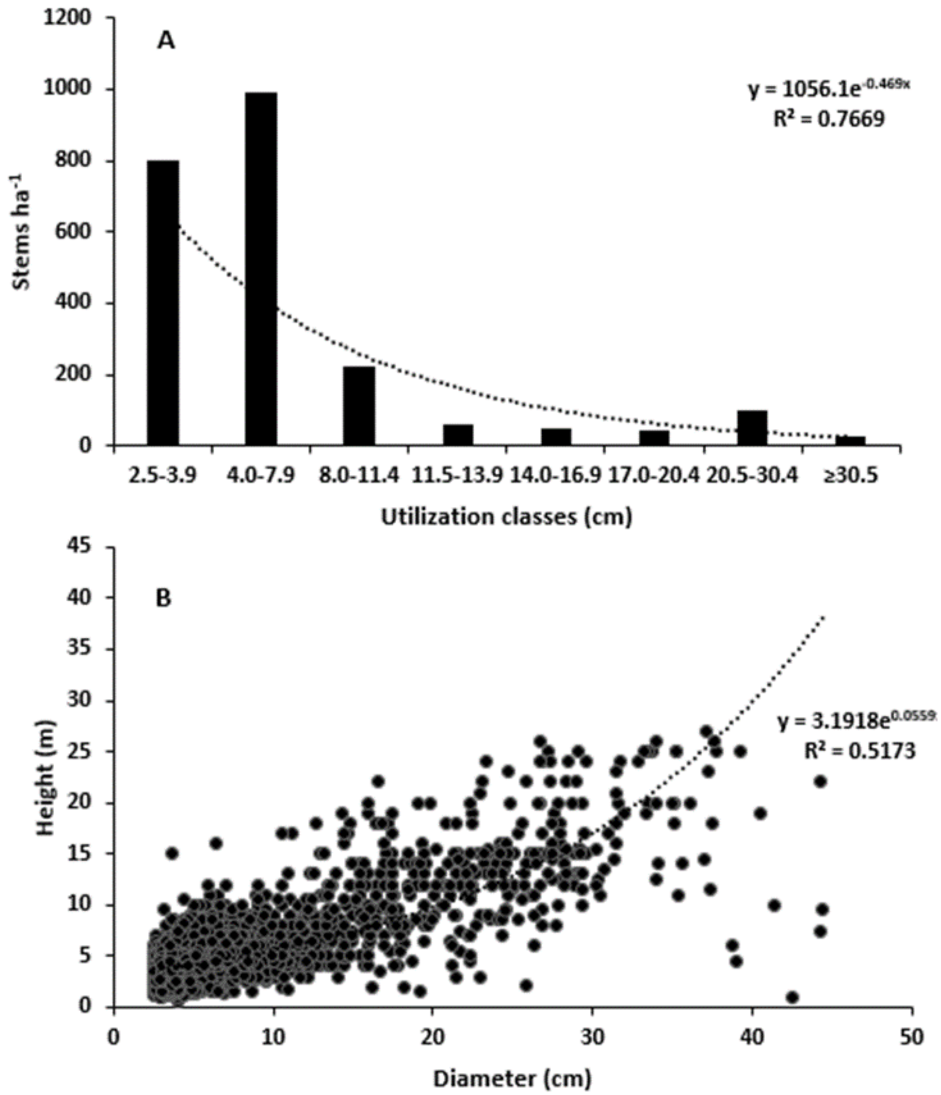

Figure 4.3: (A) Graph on size classes distribution for Northern central swamp mangroves, (B) Scattergram showing tree height against DBH of Northern central swamp mangroves.

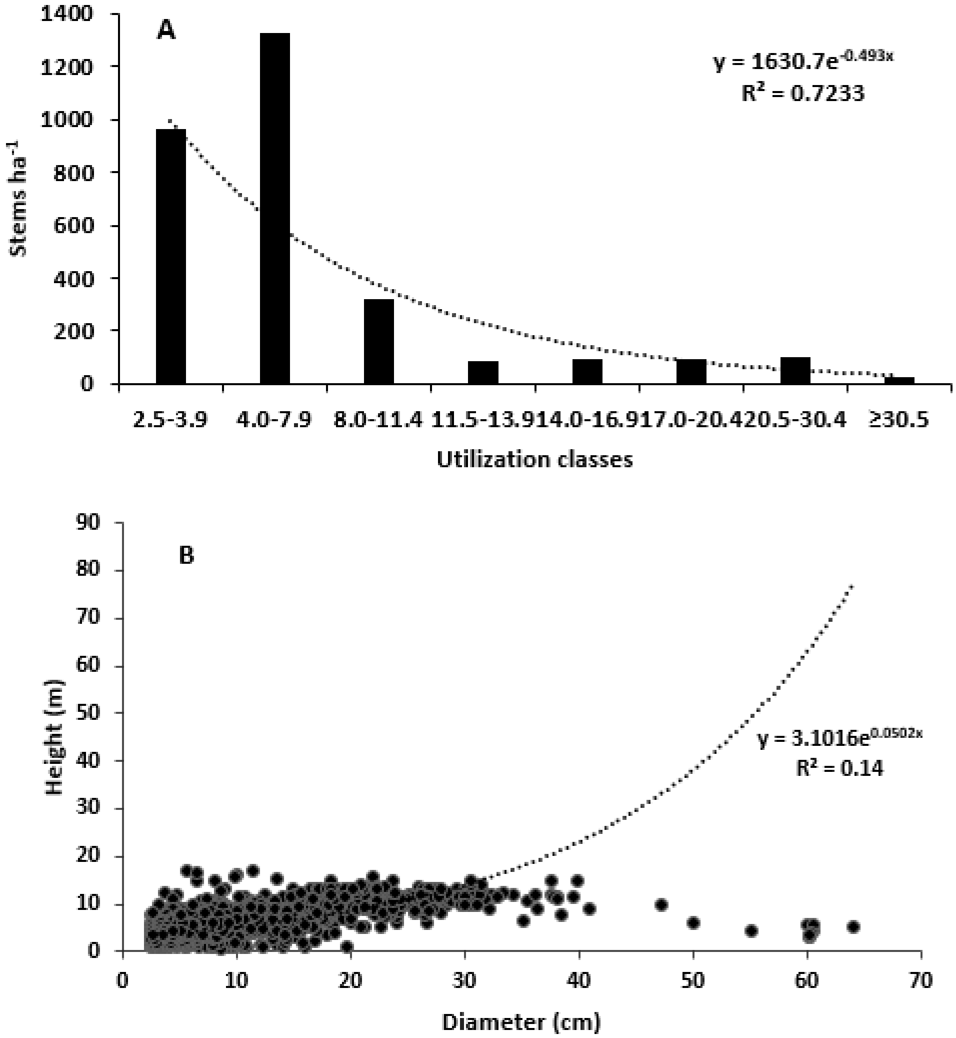

Figure 4.4: (A) Graph on the size classes distribution for Southern swamps mangroves, (B) Scattergram showing tree height against DBH of Southern Swamps mangroves (Rm, Ct).

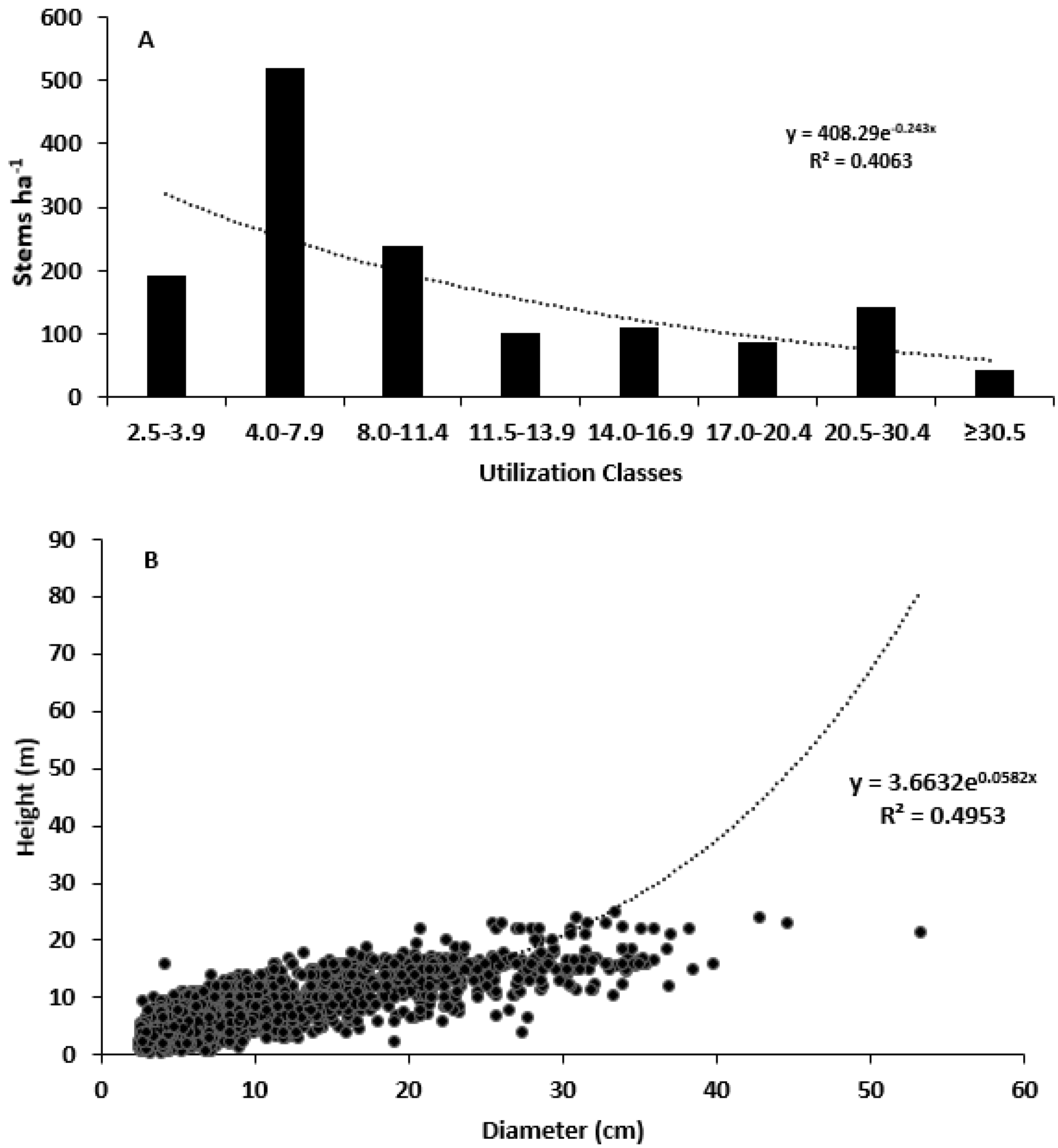

Figure 4.5: (A) Graph on size classes distribution for Northern Swamps mangroves (B) Scattergram showing tree height against DBH of Northern Swamps mangroves (Rm, Ct).

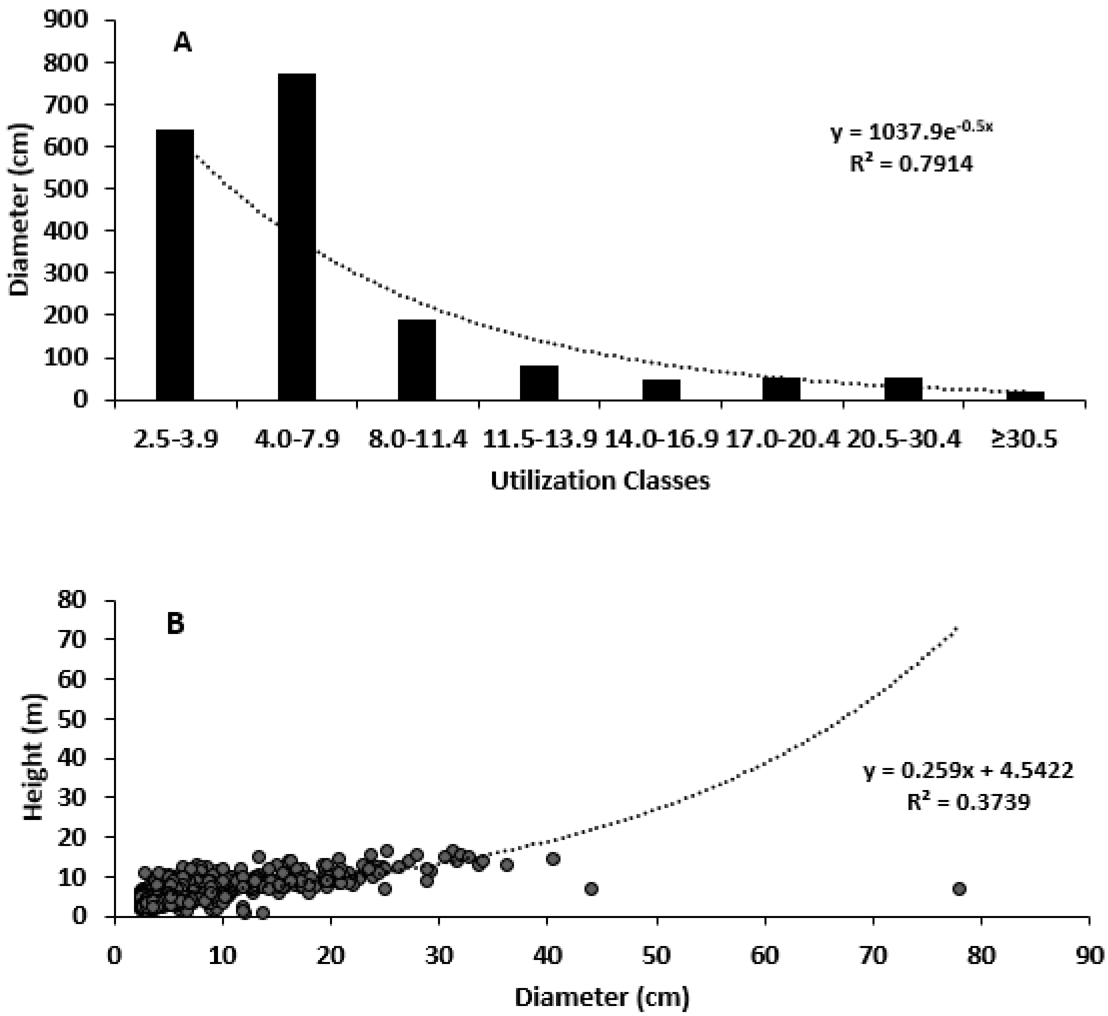

Figure 4.6: (A) Graph on size classes distribution for Mongoni-Dodori creek mangroves, (B) Scattergram showing tree height against DBH of Mongoni- Dodori Creeks mangroves (Rm, Ct).

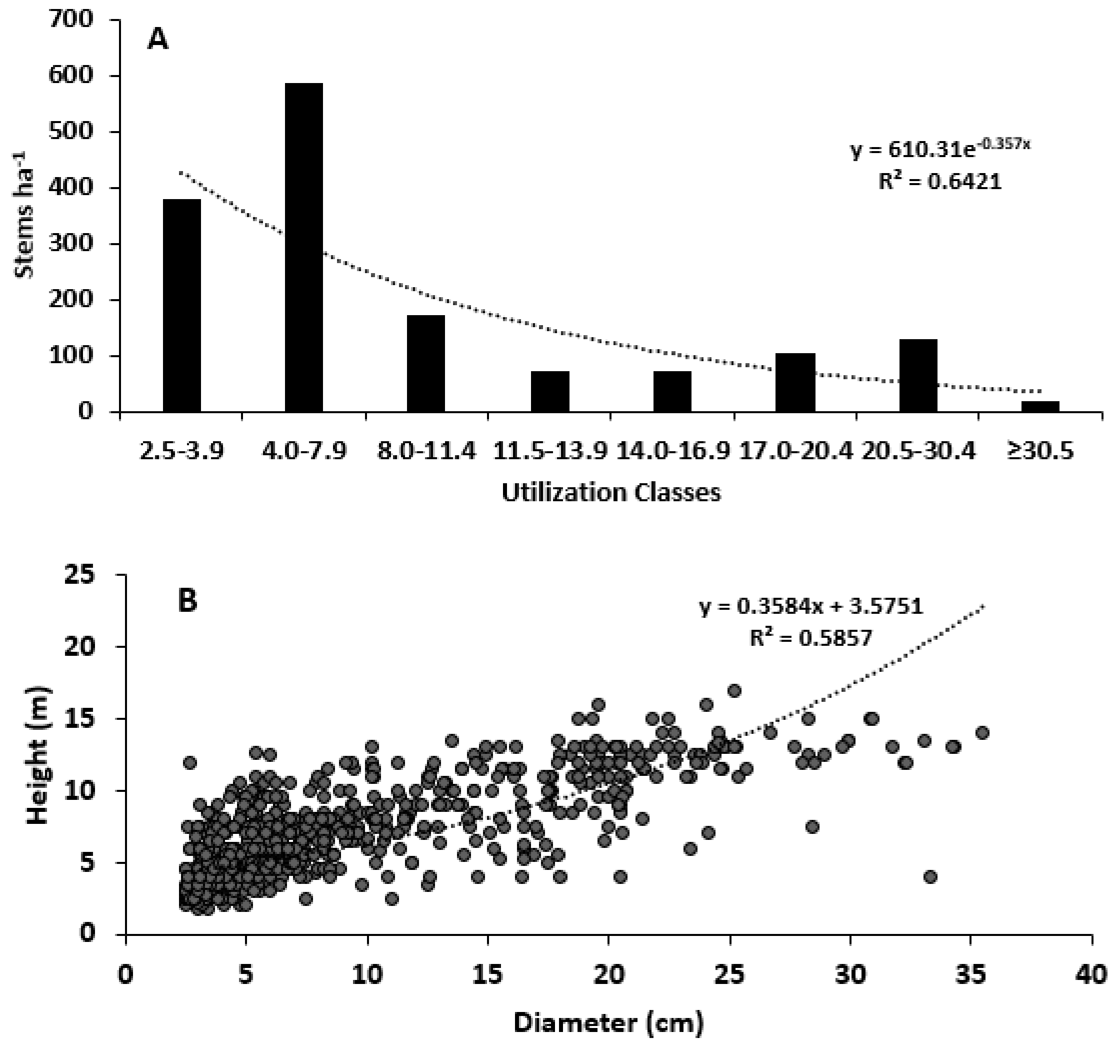

Figure 4.7: (A) Graph on size classes distribution for Pate Island swamps mangroves, (B) Scattergram showing tree height against DBH of Pate Island swamps mangroves (Rm, Ct).

4.2. Patterns of mangrove wood utilization in Lamu County.

Patterns of harvest data and allowable cut from Lamu mangroves are given in Fig. 4.8. Looking at the 26 years data [1998-2018], one can conclude that mangroves in Lamu are being underexploited (Fig 4.8). The highest number of poles removed from the forest was about 20,000 scores in 2014 against allowable cut of 240,000 scores. This is contrary to stand level data that has depicted a forest devoid of merchantable poles (Table 4.3). Most of the management blocks are stocked with non-merchantable mangrove poles an indicator of human pressure (Table 4.3).

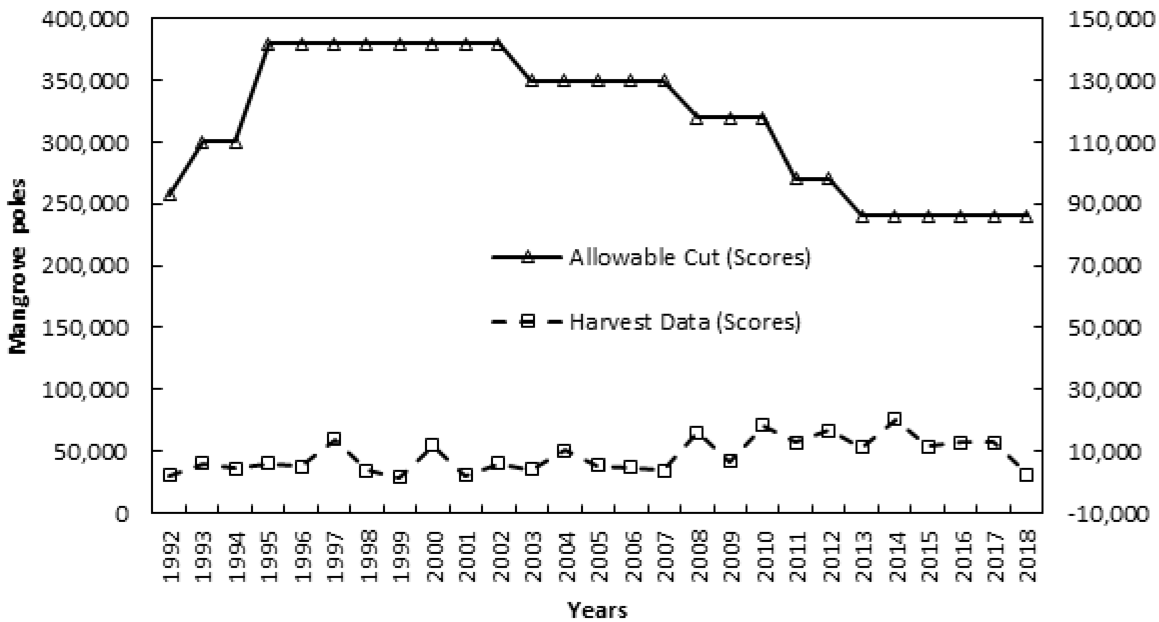

Figure 4.8: Mangrove poles harvesting (scores year-1) from 1992- 2018 in Lamu, Kenya showing allowable and actual harvests. (1 score = 20 poles). Values on the y-axis show allowable cut while z-axis show harvest data.

4.3. Pricing of mangrove poles and various charges

Market prices of mangroves poles in Kenya vary with size classes, pole quality, as well with demand. *Nguzo* sized poles fetches the highest prices followed by *vigingi, boriti, mazio* and *pau* (Table 4.5). Overall, products sold in Malindi fetch better prices than other coastal towns (Table 4.5). The variation in prices at the different urban centers is due to demand and the additional costs incurred during transport. *Fito* are allowed to be harvested but are consumed locally in filling the walls of traditional houses. Costs incurred by actors in Mokowe and Ndau did not vary since they are exposed to the same environment. Malindi, Kilifi and Mombasa are the urban centres where the mangrove poles stockists do trade. Watamu is located in Kilifi County hence profits and costs for the stockists here were expressed as part of those in Kilifi.

Table 4.5: Mangrove poles average prices (±SE) in the three major urban centres where they are sold to the final user (USD/score) 1USD= Ksh 107.33.

Utilization class	Kilifi	Malindi	Mombasa
Boriti	46.17±1.75	52.29±3.82	49.61±2.75
Mazio	30.2±2.12	35.64±2.24	28.88±3.28
Pau	27.74±1.40	21.55±1.19	25.16±0.93
Nguzo (Nguzo 3)	64.60±1.76	68.01±1.93	63.59±0.74
Vigingi (Nguzo 1 and Nguzo 2)	49.90±1.58	56.14±3.00	55.90±4.65

Costs imposed on the poles at the landing site include forest levy, tax and movement permit fee. Forest levy charges vary depending on pole size classes per score while movement permit is charged depending on tonnage of the poles (Table 4.6). 14% of the total forest levy is charged as government tax.

Table 4.6: Forestry levy charges. (1USD= Ksh 107.33) (Foreign exchange rates August 2020).

Utilization class	Diameter range (cm)	USD/score
Nguzo (Nguzo 3)	20.5-30.4	5.59
Vigingi (Nguzo 1 & Nguzo 2)	14.0-20.4	5.59
Boriti	11.5-13.9	4.66
Mazio	8.0-11.4	3.73
Pau	4.0-7.9	1.86
Fito	2.5-3.9	0.56

4.4. Costs, revenue and profit margin along mangrove wood value chain

Licensees hire cutters who carry out selective logging of mangrove poles. There are currently some 415 mangrove cutters registered under the 22 licensees in Lamu County. Only 13 licensees were active during the study period. Commercial mangrove harvesting is male dominated. At least 85 % of the respondents reported that pole logging is a tedious activity hence only men do it while females engage in firewood collection for subsistence use (Table 3.2). A group of 4-6 cutters work together and can stay in the forest for 4-5 days harvesting poles which is done twice per month to coincide with spring tides. During this period the group harvest about 113 scores.

Net profit varies along the value chain among the different actors. The national regulator, KFS, receives the highest monthly income of USD 2,587.8, followed by licensee in Mombasa (USD 1,809.5), Malindi (USD 1,705.4) and Kilifi USD (1,698.1). *Jahazi* transporter receives USD 1,291.9/month, whereas a stockist in Malindi, Mombasa and Kilifi get a monthly income of USD 359.1, 323.8 and 307.0 respectively. Each lorry transporter receives a monthly income of USD 170.04 with a Cutter receiving only USD 118.6 for the same period (Table 4.7).

Costs associated with mangrove trade include annual harvesting permit, forestry levy, national tax, movement and business permits, county cess and municipality tax. The profit margin across the value chain is statistically significant ($p<0.05$).

Table 4.7: Monthly mean net incomes (±SE) for the various actors in the mangrove wood value chain. The Kenya Forest Service is the main regulator of the chain and its net income include various levies. Amounts are in USD (1 USD = Ksh 107.33).

Actors	**Cutter**	**Lorry Transporter**	**Jahazi transporter**	**KFS**	**Urban centers**	**Stockist**	**Licensee**
Net income	118.6±17.9	170.0±37.6	1291.9±119.6	2587.8±93.4	Kilifi	307.0±91	1698.1±292
					Malindi	359.1±166.5	1705.4±293
					Mombasa	323.8±80.2	1809.5±311

A cost benefit analysis amongst the actors in the value chain show cutters and Jahazi transporters have the least cost benefit ratio. (Fig 4.9)

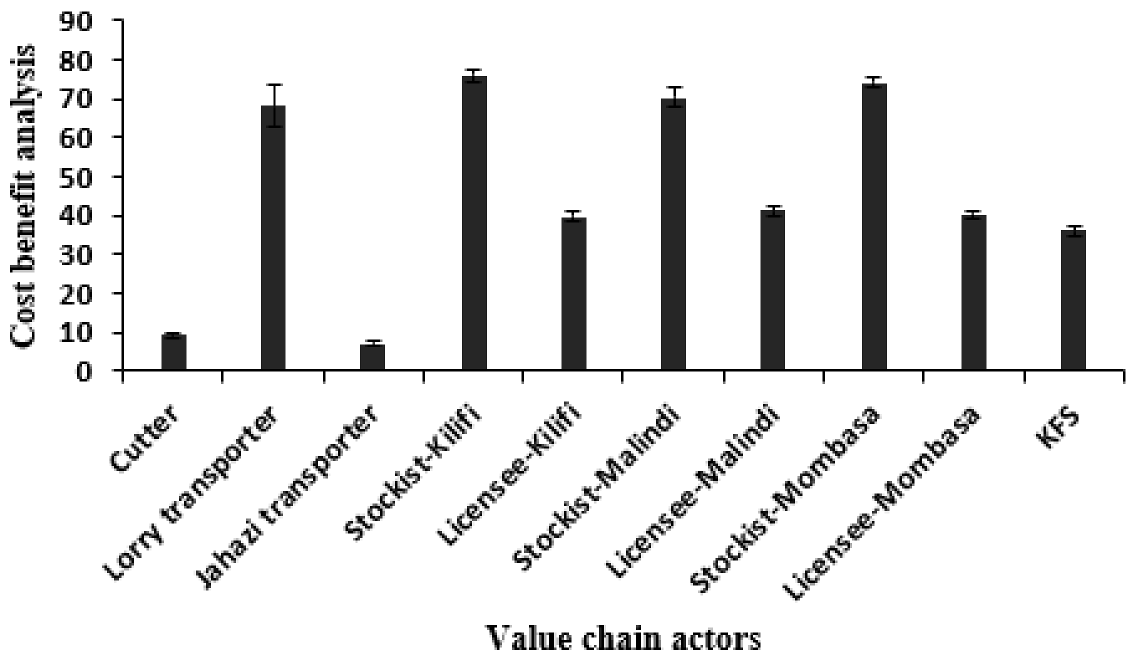

Figure 4.9: Percent cost-benefit ratio amongst actors in the mangrove wood value chain.

CHAPTER FIVE

DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1. Stocking rates of Lamu County mangroves

This study recorded six mangrove species out of the nine reported in Kenya and the ten reported in WIO region (Kairo et al., 2009; Samoilys et al., 2015). The species displayed horizontal zonation with *Rhizophora mucronata* and *Ceriops tagal* being the most dominant. The observed zonation pattern is typical of mangroves zonation in Kenya, which starts with *Sonneratia alba* on the seaward margin, followed by large *Avicennia marina* and *Rhizophora mucronata*, then *Ceriops tagal* (Kirui., 2013; Government of Kenya, 2017). The same has been observed in related studies in Mida creek, Mtwapa creek among others (Kairo et al., 2002, Okello et al., 2013). The high dominance of *Rhizophora mucronata* can be attributed to local climatic conditions which favor the species, vivipary mode of reproduction, capacity to regenerate easily, ability to colonize inundated substrates and to withstand siltation due to the mass of its large propagule (Mohamed et al., 2009). *Ceriops tagal* and *Rhizophora mucronata* having higher importance values are most harvested. This is in line with other studies which report availability of the resource as the main contributing factor for harvesting pressures (Dahdouh-Guebas et al., 2000; Scales & Fries, 2019). The trees are harvested for building and construction poles as well as for wood fuel.

Basal area has been used as a measure to determine the level of disturbance of forest stands in previous studies (Ellison, 2015; Komiyama et al., 2008). A forest with low or no disturbance shows larger basal area 25m^2 ha^{-1}, a secondary forest has 15m^2 ha^{-1} while a harvested forest has about 10 m^2 ha^{-1} (Komiyama et al., 2008). The basal areas in this study for all species except *Rhizophora* indicated values below 10 m^2 ha^{-1} which is a characteristic of a harvested forest. The tree size classes general distribution for *Ceriops tagal* and *Rhizophora mucronata* in the 5 blocks, shows reversed J- shaped curves which is a common distribution for a natural forest. The stem density decreases as diameter increases which is in agreement with a study by (Allen et al., 2001), in the mangroves of Pacific Island of Kosrae which showed that in areas without large-scale harvesting, the stem density versus the diameter distribution of trees results in a nearly perfect J-shaped curve. Forests where frequent harvesting is practiced show a reduced number of smaller diameter trees (Allen et al., 2001).

Generally, the stocking rate of Lamu mangroves indicate a forest at risk of being degraded in terms of quality of poles and distribution of utilization sizes. *Nguzo 1* and *nguzo 2* (*vigingi*) are the least abundant in the 4 blocks (46 and 43 stems ha^{-1}) respectively followed by *boriti* (11.5-13.9 cm) 47 stems ha^{-1}, *nguzo 3* ('*Nguzo*') (20.5-30.4 cm) 58 stems ha^{-1} and then *mazio* (8.0-11.4 cm) 117 stems ha^{-1} (Table 4.4). The Northern central swamps where harvesting is intense, recorded the lowest density of merchantable poles ha^{-1} in most marketable size classes (*boriti, vigingi, mazio*) (Table 4.3). The Southern swamps have the highest density of non-merchantable poles ha^{-1} followed by Pate Island swamps and then northern central swamps (43%, 37% and 36% respectively (Table 4.3). This can be attributed to the intense selective logging in these areas by both licensed and illegal cutters. Clear-felling for fuelwood was noted in Pate Island swamps as also reported by (Osuka et al., 2016). A recent study by (Okello et al., 2022) on structure of mangrove forests of Kiunga - Pate conservancies has reported unregulated cutting of trees mainly in areas within northern central swamps and Pate Island swamps as the reason for the high density of non-merchantable poles.

In all the five sites (Northern central swamps, Dodori-Mongoni creek swamps, Pate Island swamps, Southern swamps and also Northern swamps), the stocking rates was dominated by smaller diameter poles *fito* 2.5-3.9 cm and *mazio* 8.0-11.4 cm (Table 4.3) and non-merchantable poles (crooked poles) unsuitable for construction hence compromising the forests' potential for future exploitation. The selective logging for poles has impacted the quality and stability of the forest. A similar observation was made for the mangrove forest of Kenya by an earlier study (Kairo, 2001). *Boriti* sized poles are the most desired in the market hence mostly harvested, followed by *nguzo 2* (*vigingi), mazio* and then *nguzo 3* (*nguzo*). This utilization classes preference implies that with continued selective logging, in the long run, the forest could get depleted of these pole size classes. Selective harvesting results to imbalance in size classes which could make the forest structurally poor in terms of utilisation (Kairo, 2001).

5.2. Mangrove wood harvesting pattern in Lamu County

The harvest trend established from the KFS data records indicate that the Lamu mangrove forest is underexploited (Fig 4.8) yet from the actual inventory data obtained during this study, most of the forest is at a risk of degradation in terms of quality of poles and stocking rates of the size classes across the management blocks (Table 4.4). The allowable harvest appears way much more than the removal pattern for the period between 1992-2018 (Fig 4.8) hence does not match the stand data which shows a forest at a risk of degradation (Table 4.3). This suggests that KFS could have set the allowable cut at an unsustainable level or there could be gaps in forest governance in regard to recording of the harvested poles, tracking of logged poles, predictions on amounts to be removed (allowable harvest) from the forest without adequate assessment of the actual forest condition or the sampling procedures. If at all the allowable cut is not met nor exceeded, then the yield of Lamu mangroves could be so high and would deviate from a characteristic of a forest stocked with non-merchantable poles and imbalanced distribution of size classes (Fig 4.8; Table 4.3). The implementation gaps in KFS such as failure to fully comply with the laid down harvesting rules by licensees and cutters could be due to vices such as corruption as reported in a study on forest governance by Kairu et al. (2018).

Nguzo 3 (20.5-30.4 cm) (commonly referred to as *Nguzo*) poles fetch highest prices in the market but are the least preferred due to their large size and the fact that *Nguzo 1 and 2* (*vigingi*) are more readily available in the forest and can be alternatively used for making fences and covering of pit latrines. *Vigingi* prices are second highest followed by *boriti*, *mazio* and least *pau* (Table 4.5). These prices differ from results by (Curtin, 1983) in a study done in Lamu which recorded *boriti* selling at the highest price and *mazio* selling at half the price of *boriti*. This difference could be due to the changes in economic conditions over time, resulting in changes in the relative demand for the different size classes. *Nguzo 1 &2 ('vigingi')* and *boriti* are the most marketable size classes. *Mazio* and *boriti* are reported as the most marketable size classes in other studies (Kairo, 2001; Kairo et al., 2002; Atheull et al., 2009). *Boriti* is used for house construction hence its high demand mostly in urban centres (Kairo., 2001; Kairo et al., 2002).

5.3. Mangrove wood value chain

In this study, the route followed by mangrove poles is; from cutters, the licensee (wholesaler), the stockists (retailers) and finally the consumer. The licensees are the primary buyers since they buy from the cutters and then sell to the secondary buyers (pole stockists) in various urban centres who in turn sell to the final consumers. Transporters ferry the poles from the cutters to the licensee (mostly by dhows) and also supply the poles from the licensee (at landing site mostly by lorries) to the stockists in various urban centres. Mangrove value chain in several other studies reported similar actors as in the current study (Curtin, 1983; Njie, 2011; Rosales et al., 2017; Machava-António et al., 2020). The actors are linked by the market which involves wholesalers, traders, middlemen, suppliers and service providers. Licensees serve as the link between mangrove cutters to the market. Such linkage has been recorded in studies elsewhere (Zafar & Ahsan, 2006; Njie, 2011; Rosales et al., 2017). A similar study in Central Mozambique by (Machava-António et al., 2020) recorded a similar route of the mangrove poles in addition to other routes in the same study where in the common one, harvesters sell directly to the final consumer.

Studying the chain shows why pressure on natural resources can lead to degradation (Bandeira et al., 2016a) and unsustainable exploitation (Masalu, 2003) hence its significance in streamlining the trade for sustainable use of the resource. Ecosystem valuation plays an important role in making informed decisions in ecosystem conservation (Daily et al., 2009; TEEB, 2010; Mukherjee et al., 2014; Guerrya et al., 2015).

Economic valuation studies of mangrove ecosystems in Asia estimated the value of mangroves at - USD 57,000 per ha $year^{-1}$ (Hoegh-Guldberg et al. (2015). In Mozambique, the minimum value of mangroves wood products is estimated at USD 2400 ha^{-1} (Machava-António et al., 2020). There’s recognized knowledge gap of valuation studies in Western Indian Ocean (WIO) region (Vegh et al., 2014). The overall value of mangroves in WIO region has been estimated at US$ 42.7 billion (Obura et al., 2017).

This study, recorded 1,361 merchantable stems ha^{-1} of *R. mucronata* and *C. tagal* in Lamu mangroves forest excluding Northern swamps. Out of this, *fito* were 480 stems ha^{-1}, *pau* 555 stems ha^{-1}, *mazio* 118 stems ha^{-1}, *boriti* 47 stems ha^{-1}, *vigingi* 89 stems ha^{-1} and *nguzo* 58 stems ha^{-1}. On average the *fito* prices were USD 18.62 $score^{-1}$, *pau* USD 24.82 $score^{-1}$, *mazio* USD 31.57 $score^{-1}$, *boriti* USD 49.36 $score^{-1}$, *vigingi* USD 53.98 $score^{-1}$ and *nguzo* USD 65.4 $score^{-1}$. From this, the value of Lamu mangroves poles can be estimated at USD 1,847.76 ha^{-1} which is a lower value than that recorded by (Kairo et al., 2009) in a study on economic analysis in replanted forest in Gazi Bay, which reported the value of poles of 12-year-old *Rhizophora* plantation to be US$4,328.27 ha^{-1}. The low estimated economic value of Lamu mangrove poles contradicts the results on harvesting trend which indicates under exploitation of the forest.

5.4. Actors' income, costs and profits in Mangrove Wood Value Chain

The profits accrued and expenses incurred by the actors vary along the value chain (Wamukota et al., 2004). A similar observation was made in other studies (Kaplinsky, 2000; Kaplinsky & Morris., 2001; Machava-António et al., 2020) which also recorded variation in profits and costs incurred by the various stakeholders in the chain. The profits variation for the different actors (Rosales et al., 2017) contributes to the willingness of people to engage in mangrove marketing (Vegh et al., 2014) and at various stages of the value chain (Adeyemi et al., 2012; Lowitt et al., 2015).

Observations on the profit margins alone, the 'winners' in mangrove trade are KFS and licensees, whereas the cutter gets the *least* income (Table 4.7). Due to the low literacy levels of the cutters, they are not well informed on the dynamics of the market and their rights hence end up being exploited. Cutters do the tedious work of harvesting mangrove poles yet receive the least net income (Table 4.7). Similar observations were made in a mangrove wood value chain study in Mozambique (Machava-António et al., 2020) where mangrove harvesters received least payment. Most of the KFS expenses in mangrove trade are cautioned by the government through paying of salaries and for patrols; as such they are not captured in the mangrove wood value chain.

5.5. Conclusion and recommendations

Harvest data on mangroves in Lamu county depicts an underexploited forest. This contradicts with the actual stock data which indicate a forest at risk of degradation. Most of the management blocks are stocked with non-merchantable poles and imbalanced distribution of size classes. Lamu mangrove forest is overexploited. The contradiction between the forest condition as reported by KFS records and stock level data points to a governance challenge. Most preferred pole size classes (*boriti* and *vigingi (nguzo 1 & 2*) are the least abundant across the blocks.

In the mangrove wood value chain, there are great variations in the profit margins across actors.

Mangrove trade need to be monitored to ensure supply meets the demand. Developing and implementing mangrove harvest plans would ensure the forest restock itself following disturbance. Monitoring by KFS and other stakeholders would ensure adherence to harvest guidelines and restoration plan. The results of this study provide insights towards streamlining mangrove trade to ensure improved livelihood and resource sustainability.

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LIST OF APPENDICES

Appendix 1: Research Questionnaire

I'm Purity Riungu, an MSc student at University of Embu. I'm carrying out a study on determining sustainability of mangrove wood resources and the value chain in Lamu County, Kenya. This questionnaire is purely for academic use.

Part 1: General information

Name ……………………… Role in relation to mangroves ………… Village…...

1**. Age** ……………. **2. Gender** a) Male b) Female

3. **Education Level**

a) None /Madrassa b) Primary (complete/incomplete)

c) Secondary (complete/incomplete) d) Tertiary College/University

4. **Occupation**

a) Farmer b) Civil servant c) Self-employed d) Student

f) Any other-specify………………………………………………………….

5. Duration of stay in Lamu

a) 1-3years b) 4-10 years c) Above 10 years

Part II: Authorization and harvesting procedure of mangrove wood resources

1.How does one acquire authorization to harvest mangrove wood?

2. How much does one pay for licensing by KFS? What period?

3.What amounts are allowed to be harvested in a specified area over the licensed period? Where are you doing the harvesting?

4.How many people are involved in harvesting operation and for how long?

5.How many times do you harvest mangrove wood products per month? How many scores per harvest?

6.Which are the sizes of trees allowed to be harvested? (KFS official) (Cutter- what pole sizes do you harvest)?

7.In your opinion, what determines the market prices of mangrove wood products?

Wood product	Determinants (species, size, thickness, form (straight/crooked)
Timber	
Poles	
Charcoal	
Firewood	
Any other	

8.What are the current price ranges for the various mangrove wood products? (licensee/stockist/local sellers)

Product		***Measurement unit***	***Price***
Poles	a) Boriti b) Mazio c) Pau d) Fito e) Nguzo		
Timber			
Charcoal			
Firewood			

9.Which are the landing sites*? (licensee)*

10.How much is the cutter paid per day/score? *(cutter/licensee)*

11.Which tools are used in harvesting mangrove wood? *(cutter/licensee)*

a) Hack saw b) Axe c) Panga d) Power saw e) any other

12.Where do you get the harvesting tool from and at what cost? *(Hire or buy*) *L/C*

13.What is the cost of transporting wood products to the shore using a boat/dhow per day/month? *(hire/own)*

16. How do the mangrove products reach the market?

17.What is the transport cost involved per score? E.g. *dhows, lorry to village, Lamu (Licensee)*

18.Other costs involved? E.g. loading, Guards, county cess

19.What amount of the mangrove wood products are traded within a month? *(KFS/Licensee)*

20. i) What pole sizes are more marketable for building and construction? Give reasons *(Licensee)*

ii) Is there any value addition on the poles or other products before sale in order to fetch more income?

21.Which is the main market Centre. Why? L/seller?

22. How long have you engaged in mangrove exploitation or trade?

23.What are the specific roles played by each of the following actors in mangrove exploitation?

Actor	***Role***	
KFS		
Licensee		
Cutters		
Transporter		
Wholesale traders		
Retail traders		
Any other (Specify)		

24.Who do you think benefits more in this trade? Why?

25.How is the business regulated to ensure maximum profits to each actor? (KFS & licensee)

26.Do you think exploitation of these resources is sustainable? *(Yes/no)*

a) Explain the response.

b) In your prediction how long, do you think the forest can remain productive at the current exploitation rates? give reason

27.What regulations are put in place to ensure sustainable harvesting of mangrove wood?

28. What are some of the challenges that you face in mangrove exploitation and the market pathway?

29.What do you think the government should do to intervene so as to ensure sustainable harvesting of mangrove wood and maximum profits to each actor?

30.How has the supply changed in the last 10 years (from forest)? R*easons*

a) No change b) increase c) Decrease d) No idea

31. How has the demand changed in the last 10 years (market)? *Reasons*

a) No change b) increase c) Decrease d) No idea

Appendix 2: Market Survey Guide

I'm Purity Riungu, an MSc student at University of Embu. I'm carrying out a study on determining sustainability of mangrove wood resources and the value chain in Lamu County, Kenya. This questionnaire is purely for academic use.

Part 1: General information

1.Name …………………….....   2. Age……………. 3. Gender   a) Male   b) Female

4. Market Centre………………...   5. Role in relation to mangroves …………………….

6. **Education Level**

a) None /Madrassa   b) Primary (complete/incomplete)

c) Secondary (complete/ incomplete)   d) Tertiary College/University

7. **Occupation**

a) Farmer   b) Civil servant   c) Self-employed   d) Student

f) Any other-specify………………………………………………………...

Part II: Value chain of mangrove wood resources

1. Is there any authorization required for one to engage in sale of mangrove wood? Yes/no

If yes mention procedure and requirements

2.What are the current price ranges for the various mangrove wood products

Product	Measurement unit	Buying price (Ksh)	Selling price (Ksh)
Poles a) Boriti b) Mazio c) Pau d) Fito e) Vigingi f) Nguzo			
Timber			
Firewood			

3.In your opinion, what determines the market prices of mangrove wood products?

Wood product	Price determinants (species, size, thickness, form (straight/crooked)
Poles	
Timber	
Firewood	

4. What is the transport cost to ferry wood products to the store per month?

5.Other costs involved? E.g. loading/offloading, Guards, county cess.

6.What amount of the mangrove wood products are traded within a month?

7. i) What pole size is more marketable for building and construction? Give reasons

ii) Is there any value addition on the poles before sale in order to fetch more income?

8.Which are the most preferred mangrove species. Why?

Mangrove use	***Preferred species***	***Reason***
Poles		
Timber		
Fuelwood		
Boat construction		

9.For how long have you engaged in mangrove trade?

10.Who do you think benefits more in this trade? Why

a) KFS
b) Licensee/ dealer
c) Cutters
d) Transporters
e) Stockists/wholesale traders
f) Retail traders

Reason;

11. Do you think exploitation of these resources is sustainable? *(Yes/no)*

a) Explain the response.

b) In your prediction how long, do you think the forest can remain productive at the current exploitation rates? give reason

12. Which challenges do you face along the market pathway?

13.What do you think the government should do to intervene so as to ensure sustainable harvesting of mangrove wood and maximum profits to each actor?

14. How has the supply changed in the last 10 years (from forest)? *Give Reasons*

a) No change b) increase c) Decrease d) No idea

15. How has the demand changed in the last 10 years (market)? *Give Reasons*

a) No change b) increase c) Decrease d) No idea

PUBLICATION

1. **Riungu, P.M.,** Nyaga, J.M., Githaiga, M.N., & Kairo, J.G. (2022). Value chain and sustainability of mangrove wood harvesting in Lamu, Kenya. *Trees, Forests and People*, 9, 100322. https://doi.org/10.1016/j.tfp.2022.100322

CONFERENCES AND SEMINARS

1. 12th WIOMSA Scientific Symposium at the Nelson Mandela Bay- South Africa from 10th-15th October, 2022.
2. Aquatic Resources and Blue Economy Conference held in Kisumu from 28th November- 1st December, 2022
3. Post-2020 Global biodiversity framework review seminar, Diani-Kwale County, June 2021.
4. Community Forest Association (CFA) and Participatory Forest Management Plan (PFMP) development workshop for Lamu mangroves from 6th to 12th September 2020**.**

PRESENTATIONS

1. Poster presentation at the 12th WIOMSA Scientific Symposium at the Nelson Mandela Bay- South Africa, October 2022.
2. Oral presentation at the Aquatic Resources and Blue Economy Conference held in Kisumu (Acacia premier hotel) from 28th November- 1st December, 2022.

Plate **a:** Interview with a licensee, (**b)** Interview with a pole stockist in Malindi.

Plate **c**: Site visit to a harvesting area in Lamu mangrove forest (**d)** Degraded site in Manda island- Lamu mangrove forest.