UNDERSTANDING CHANGES IN MANGROVE FORESTS AND THE IMPLICATIONS TO COMMUNITY LIVELIHOOD AND RESOURCE MANAGEMENT IN KENYA

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ABSTRACT

Mangrove forests support the livelihoods of many coastal communities in developing countries. Mangrove forests around the world are being lost due to a combination of human and natural pressures. There is an intricate relationship between resource use and degradation and resource-dependent communities. Dependency on resources can lead to an ecosystem's degradation if management disregards local people's needs. Degraded mangroves are more vulnerable to environmental changes and may be less able to provide the ecosystem services and goods that are crucial to the livelihood of local people. The key outcome of sustainable resource management is to identify ways to improve both environmental quality and the living conditions of the local communities. Therefore, the sustainable management of mangrove forests requires an understanding of: (a) how mangroves are used by local communities; (b) the local perceptions of changes happening in the mangrove areas and (c) how changes in mangroves are affecting local livelihoods including adaptation options. Focussing on coastal Kenya and using Lamu as a case study, this multi-method research used systematic literature review, household surveys, participatory consultation workshops, land use land cover change analysis, and ecosystem services modelling to understand local mangrove uses, perceptions of change in mangroves and the implications to uses and users, including adaptation options. The thesis first provides an overview of mangrove ecosystem services and the global utilization of mangrove resources. The contribution of mangroves to fisheries is the most researched ecosystem service followed by habitat use and carbon sequestration and storage. The review indicates that wood used for construction and fuel is the mangrove resource most often mentioned in the literature, and it is often associated with the loss of mangrove forests. A survey conducted in 592 households in five locations in Lamu county noted high levels of dependency on mangrove forests and varying perceptions about changes in mangrove areas and drivers of change. The variation is noted across gender, occupation, and location of respondents. Most of the respondents indicated a perceived increase in mangrove cover in the last decade. In contrast, an analysis of land cover data shows a decrease in mangrove cover in Lamu county and Kenya at a very slow rate (0.01% annual average between 2010-2019), with areas closer to settlements exhibiting higher deforestation rates. Mangrove loss also increases the exposure of local areas to coastal hazards. Analysis using the InVEST coastal

vulnerability model indicates that 16% of the country's coastline is currently at a relatively higher risk of exposure to coastal hazards. This may increase to 25% with the loss of mangroves and to 41% if coral reefs are also lost. Although coral reefs contribute the most to reducing the proportion of the country's coastline to exposure, mangroves contribute the most in Lamu and Tana River counties. Stakeholders' consultations conducted in Lamu, Kwale and Kilifi counties identified differences between communities regarding perceived key threats and the adaptation options being employed. The threats identified during these consultations were dominantly related to human use and climate change was a lower concern. Although overharvesting of wood resources was identified as a common threat, coping strategies for this threat differ along the coast. While some counties are using an alternative source of wood, others are switching to alternative methods of construction (bricks, cement) and fuel (LPG gas). Subsidies for communities to use alternatives to mangrove products and seasonal or rotational closure of mangrove areas are some of the proposed interventions for mangrove resource sustainability. In addition, while the ban on mangrove harvesting was noted to be beneficial in Kwale county as it supported conservation efforts in place, it was observed to be detrimental in Lamu county due to traditionally depending on mangrove harvesting and use. To be effective and sustainable, the management needs to take into account local perceptions and needs and recognize differences across neighbouring communities. A framework that provides key steps that can be taken to assess adaptation needs and alternatives was developed in this study. The study also identified the need for long-term alternatives for the livelihoods of those depending on mangroves. These alternatives can only be realized if the management of mangrove areas includes opportunities to build local skills and capacity while recognising that needs vary across locations.

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AUTHOR'S DECLARATION

I declare that the work in this dissertation was carried out in accordance with the University's Code of Practice for Research Degrees and that it has not been submitted for any other academic award.

I also declare that while registered as a candidate for the university research award, I have not been a registered candidate or enrolled as a student for any other academic award. I confirm that the work presented in this thesis is my work except where indicated by specific references in the text.

LIST OF ABBREVIATIONS AND ACRONYMS

Symbol	Name
AOI	Area of Interest
ASFADA	Arabuko Sokoke Forest Adjacent Dwellers Association
BMU	Beach Management Unit
C	Carbon
CDA	Coast Development Authority
CFA	Community Forest Association
DPSIR	Drivers, Pressures, State, Impact and Response model of intervention
EIA	Environmental Impact Assessment
e.g.,	for example
etc.	Etcetera
ha	Hectares
IE	Index of exposure to coastal hazards
i.e.,	That is
InVEST	Integrated Valuation for Ecosystem Services and Tradeoffs
IUCN	International Union for Conservation of Nature
KEFRI	Kenya Forestry Research Institute
KeFS	Kenya Fisheries Service
KFS	Kenya Forest Service
KMFRI	Kenya Marine and Fisheries Research Institute
km	Kilometres
LPG	Liquefied Petroleum Gas
Mg	Megagram
mg	Milligram
m	metre
M	Millions
NGOs	Non-governmental organisations
NEMA	National Environment Management Authority
PES	Payment for Ecosystem Services
VAJIKI	Vanga Jimbo Kiwegu
WWF	World Wide Fund for Nature
yr.	year

1 Introduction

This chapter presents the background knowledge and key concepts that underpin the research covered in Chapters 2 to 5. Sections 1.1 to 1.4 offer an overview of ecosystem services, the global distribution of mangroves, threats facing them and the drivers of change, and management interventions. The importance of mangroves to people and the environment and the need for sustainable management are discussed in this chapter. Mangrove issues specific to Kenya are covered in Section 1.5 and provide problem analysis and justification of the study. The Aim and objectives of the study are covered in section 1.6, whereas the overall structure of the thesis is described in section 1.7.

1.1 Mangrove ecosystem services

Ecosystem services have been referred to as both the direct and the indirect benefits obtained by humans from the natural systems which improve human wellbeing (Daily 1998). The Millennium Ecosystem Assessment (MA) categorized ecosystem services into provisioning, regulating, supporting, and cultural services. Provisioning services are the natural products obtained from the ecosystem (e.g., food, fodder), regulating services are benefits obtained from the regulation of the ecosystem process (e.g., nutrient cycling, air quality regulation), supporting services are important for other ecosystem services (e.g., nutrient and water cycling), and cultural services refer to tangible and intangible social benefits (e.g., mental, and spiritual wellbeing) (MA 2005).

There is scientific evidence that nature can provide at least 37% of climate change solutions; and that at least 30% of Sustainable Development Goals (SDGs) cannot be achieved without healthy ecosystems (UNEP 2021). A report by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) alerts us of the worrying status and conditions of coastal ecosystems (such as coral reefs, mangroves and seagrasses), and how their losses and degradations have impacted biodiversity and food security (IPBES 2019).

Mangroves are carbon-rich ecosystems (Donato et al. 2011), that support coastal fisheries (zu Ermgassen et al. 2020), shoreline protection (Barbier et al. 2011) and the provision of harvestable wood and non-wood resources to coastal communities (Lee et al. 2014). A wide variety of ecosystem services provided by mangroves are identified in the literature (Walters et al. 2008; Donato et al. 2011;

Lee et al. 2014; Mukherjee et al. 2014) as summarised in Table 1.1. The ecosystem services provided by mangroves around the world and their significance are detailed in Chapter 2.

Table 1.1: Summary of ecosystem services provided by mangroves

Category	**Examples**
Provisioning services	Food, fodder, wood/timber, fuel, fish, medicine, tannin, dye
Regulating services	Coastal protection from storms, floods, erosion, Climate regulation
Supporting services	Nutrient cycling, soil formation, provision of habitat
Cultural services	Aesthetic value, recreation, tourism, spiritual, religious

(Sources: Friess, 2016; Lee et al., 2014; Mukherjee et al., 2014; Walters et al., 2008)

The Millenium ecosystem assessment (MA 2005) noted a global increase in the demand for ecosystem services between 1960 to 2000 due to population increase. This demand led to degradation and/or unsustainable use of ecosystem services. The Convention on Biological Diversity defines sustainable use as "*the use of components of biological diversity in a way and at a rate that does not lead to the long-term degradation of the environment thereby maintaining its potential to meet the needs and aspirations of present and future generations*" (United Nations 1992).

1.2 Mangrove biogeography

Mangroves are trees and shrubs that grow in the intertidal area of tropical and subtropical coasts (Duke 1992; Spalding et al. 2010). There are about 136,000 km^2 of mangroves in 108 countries (Spalding and Leal 2021). Mangrove distribution is strongly influenced by geomorphic and climatic drivers (e.g., temperature and moisture) (Alongi 2002; Njiru et al. 2022). Asia has the largest extent of the world's mangroves (42%), followed by Africa (20%), North and Central America (15%), Oceania (12%) and South America (11%) (Giri et al. 2011). The largest contiguous mangrove forests include the Sundarbans (Bangladesh), the Niger Delta (Nigeria), the coastlines of Northern Brazil and the Southern Papua, which together comprise 16.5% of the world's mangrove forests (Spalding et al. 2010).

Mangrove distribution falls into two biogeographical regions, the Indo-West Pacific (IWP) and Atlantic East Pacific (AEP). The IWP includes the mangroves of

East Africa, Asia, and Australia while the AEP constitutes the mangroves of West Africa, East, and West America (Alongi 2002). There are 73 mangrove species globally, the IWP region is the most diverse with 62 species, whereas the AEP has 12 species (Spalding et al. 2010). Mangroves exhibit a unique horizontal distribution of species (zonation) across the intertidal area that is influenced by salinity, soil type, and frequency of tidal flooding (Macnae 1969). Most mangrove species have developed special morphological, anatomical, and physiological adaptation strategies to survive in their harsh environmental conditions of high salinity, hot temperature, anaerobic soils, and extreme tides (Kathiresan and Bingham 2001; Alongi 2002).

1.3 Drivers of mangrove change

Mangroves are ecosystems threatened by both climate and human-induced stresses (Valiela et al. 2001; Giri et al. 2011; Feller et al. 2017). Studies have been successful in using remotely sensed data to map the extent and changes of global mangrove forests (Giri et al. 2011; Hamilton and Casey 2016; Bunting et al. 2018). Despite the previously mentioned inconsistencies in data, the presence of these freely available global mangrove data has been beneficial in understanding the spatial distribution of mangroves and changes over time (Worthington et al. 2020).

Studies show a net global loss of mangroves in the last few decades, but rates have slowed down. Goldberg et al. (2020) recorded 2.1% of global mangrove loss (3,363 km^2) an average annual rate of 210 km^2/year between 2000 to 2016. Bunting et al. (2018) recorded a loss of 6,057 km^2 (4.3%) at a rate of 303 km^2/year between 1996 and 2016. Mangrove loss varies geographically with some areas experiencing more loss compared to others (Thomas et al. 2017). Southeast Asia shows both the largest coverage and the highest rate of mangrove loss globally (Hamilton and Casey 2016; Thomas et al. 2017), attributed to the widespread aquaculture (Giri et al. 2011; Thomas et al. 2017). Between 2000 and 2012, Southeast Asia recorded a deforestation rate of 8.08% per year while the global loss was 0.16% per year (Hamilton and Casey 2016).

Over-exploitation of resources, conversion pressure, pollution and climate change are the major drivers of the loss and degradation of mangroves around the world (Alongi 2002; Spalding et al. 2010; Goldberg et al. 2020). Human-induced factors accounted for 62% of the mangrove loss observed between 2000 to 2016

(Goldberg et al. 2020) with great variations around the globe. Six countries in Southeast Asia (Indonesia, Myanmar, Malaysia, the Philippines, Thailand, and Vietnam) contributed to 80% of the human-induced mangrove loss recorded by Goldberg et al. (2020) which was due to widespread aquaculture and agriculture. Non-productive land use conversion (e.g., petroleum extraction in the Niger Delta) was the main anthropogenic driver of mangrove loss in Africa, contributing to 12% of the global loss.

The study by Goldberg et al. (2020) identifies shoreline erosion and extreme weather events as the main natural causes of mangrove loss. Sundarbans in Bangladesh and the coast of Brazil recorded significant losses from shoreline erosion while mangrove losses due to extreme weather events were evenly distributed across the globe. Nevertheless, mangrove dieback due to extreme weather events was the cause of half of the loss recorded in Oceania (Goldberg et al. 2020). Loss of mangroves has impacts on the provision of ecosystem services, e.g., increase carbon emission (Donato et al. 2011), decreased fisheries (Tran and Fischer 2017) and increased coastal erosion (McIvor et al. 2015). Thomas et al. (2017) noted a need to manage mangroves as multiple-use systems for climate, community and biodiversity benefits.

1.4 Sustainable mangrove management

The complexity of the mangrove ecosystem requires an ecosystem-based approach to management (Macintosh and Ashton 2003) guided by appropriate policy, legal and institutional frameworks (Macintosh and Ashton 2003; Van Lavieren et al. 2012). Macintosh and Ashton (2003) in their code of conduct to mangrove management emphasise the importance of recognising and supporting the needs of mangrove-dependent communities while promoting conservation and rehabilitation of the mangrove ecosystems. In addition, to ensure the long-term sustainability of mangrove resources, management measures should consider traditional knowledge and/or cultural values, and available scientific information (Macintosh and Ashton 2003).

The loss of mangrove forests and the subsequent impacts on the provision of ecosystem services has triggered efforts to protect, conserve, restore and use mangroves sustainably (UNEP 2014; Schmitt and Duke 2016). These efforts involve measures at both national and local scales but have proven to be successful at a local scale (Schmitt and Duke 2016). In their analysis of mangrove management intervention around the world, Schmitt and Duke (2016) noted that the conservation of existing mangrove forests is more effective than planting new forests. They identified incentive schemes such as Payment for Ecosystem Services (or PES) as a feasible tool to conserve mangrove ecosystems though requiring best practice solutions for different settings.

Reversing mangrove loss and the growing vulnerability of coastal peoples requires government commitment to develop and implement high-level policies (Van Lavieren et al. 2012). However, in many cases, existing national frameworks target the environment or forests in general and not specifically mangroves (Schmitt and Duke 2016). One fundamental consideration in management is recognising the connectivity of mangroves and other ecosystems (e.g., coral reefs, seagrasses) which is achieved through integrated Coastal Zone Management (ICZM). ICZM recognizes the ecosystem links whilst integrating and managing them across sectors and stakeholders, promoting coordination and clear distribution of responsibilities (UNEP 2014). Schmitt and Duke (2016) noted that management interventions in most countries have been carried out by respective government bodies only. This kind of intervention has proven not to be effective due to implementation challenges such as limited manpower and funding to enforce compliance and the risk of upsetting local people whose livelihood is dependent on mangrove forests. These challenges have been minimised by the introduction of community participation in mangrove management (Schmitt and Duke 2016).

Resource scarcity and changes in ecosystems have both acted as incitements throughout human history for social and technological innovation (Adger et al. 2009). Adaptation entails actions (adjusting activities, life courses and location) undertaken by individuals, communities, and societies to maintain the capacity to deal with changes in the environment (Nelson et al. 2007). Adaptation measures can significantly reduce losses attributed to climate and environmental changes (Gilman et al. 2008). Adaptation is more effective when devised and implemented through participatory approaches (Ellison 2014). These should involve the individuals who are constrained by regulatory structures, property rights and culture, governments (local and national) and international bodies (Adger et al. 2005). However, adaptation to changes is endogenous to society and hence dependent on ethics, knowledge, attitude to risk, and culture (Adger et al. 2009).

Adaptation planning in mangroves should include the resource dependants and the system in adjusting to changes in the ecosystem, to moderate potential damages and take advantage of the opportunities emerging from the changes (Ellison 2014). Sustainable use of resources and the development of alternative livelihoods are vital in reducing mangrove loss and degradation in areas where people highly depend on mangrove forests for their livelihood (UNEP 2014). Adaptation to changes in mangroves is addressed further in Chapter 5.

1.5 Research location and its significance

The Kenyan coastline is about 600 km long, extending from Somalia's border in the north to Tanzania's border in the South between latitudes 1.7°S and 4.7°S and longitudes 41.5°E and 39.2°E (GoK 2018). Coastal Kenya is generally a dry area with an average temperature between 24°C to 30°C. North Kenya has lower annual average rainfall (500-900 mm) and higher annual average evaporation (1,650-2,300 mm) than the South (1,000-1,600 mm of rainfall and 1,300-2,200 of evaporation) (Ferguson 1993). The two longest rivers in Kenya (Tana and Sabaki) originate from the highlands and drain into the Indian Ocean (GoK 2018). The presence of creeks, deltas and sheltered bays and lagoons favour the development of mangroves.

Mangroves are found in all five coastal counties in Kenya (Figure 1.1) covering an area of 61,000 ha representing 3 % of gazetted forest and 1% of state land (GoK 2017). Kirui (2013) estimated coverage of 46,590 ha in 2013. This inconsistency in the estimation of mangrove coverage is partly due to different remote sensing data sources and partly due to different methods of image classification (Xu et al. 2022). This issue is addressed in Chapter 4 focusing on Lamu county. Nine mangrove species are found in Kenya, with the dominant species being *Rhizophora mucronata*, *Ceriops tagal*, and *Avicennia marina* (Table 1.2).

Table 1.2: Mangrove species in Kenya and their uses

Species name	**Local names**	**Uses**
Avicennia marina	Mchu	Timber for furniture, fuelwood, fencing, insecticides, honey, animal fodder
Bruguiera gymnorrhiza	Muia	Construction poles, firewood, charcoal, boat paddles
Ceriops tagal	Mkandaa	Construction poles, firewood, paddles, dyes, fishing traps, animal fodder, tea
*Heritiera littorali*s	Msikundazi	Charcoal, firewood, building wood, timber for making boats
Lumnitzera racemosa	Kikandaa	Charcoal, firewood
Rhizophora mucronata	Mkoko	Construction poles, dye, firewood, charcoal
Sonneratia alba	Mlilana	Firewood, charcoal, timber for window and door frames, boat ribs, paddles, fishing floats
Xylorcarpus granatum	Mkomafi	Timber for furniture, window and door frames, charcoal, firewood, ointments, carvings
Xylocarpus mollucensis	Mkomafi dume	Fencing poles, firewood

(Sources: Semesi 1998; Dahdouh-Guebas et al. 2000; Rönnbäck et al. 2007)

Typical zonation patterns are established by mangroves in Kenya with *Sonneratia alba* and *Rhizophora mucronata* occupying the lowest intertidal zones; this is followed by *Ceriops tagal* and *Avicennia marina* in the middle intertidal areas and; *Lumnitzera racemosa* and *Heritiera littorali*s in the landward side. *Bruguiera gymnorrhiza* does not form distinct zonation in Kenya but occurs interspersed with *Rhizophora* and *Ceriops*. *Avicennia* display double zonation, i.e., it appears in abundance in two different zones (the lower intertidal and the landward side) (Ruwa 1993). Coastal communities in Kenya are strongly dependent on the mangrove ecosystem for their livelihood (Abuodha and Kairo 2001; GoK 2018). Mangrove utilization in Kenya has been based on harvesting resources, especially wood products (GoK, 2017). For centuries, mangrove poles from Kenya have been an important trade commodity to the Middle East with 24,150 scores (483,000 poles) per year exported from Lamu forests by the beginning of the 20th Century (Rawlins, 1957). This export increased to an average of 35,451 scores between 1941 and 1956 and then dropped to 13,774 scores in the period 1991-1996 (GoK, 2017). At present, wood and non-wood mangrove resources in Kenya are being harvested for subsistence and commercial uses (Dahdouh-Guebas et al., 2000, Owuor et al., 2017).

Mangroves in Kenya are being lost and degraded due to a combination of human and natural induced factors, ranging from over-harvesting of wood products to conversion to other land uses, particularly for agriculture, salt extraction, and infrastructure development (Bosire et al. 2016). Between 1985 and 2010 Kenya recorded a total mangrove loss of 18% or 0.7%/yr (Kirui et al. 2013). Natural factors such as *El Niño* and sedimentation are also associated with mangrove degradation in Kenya (Bosire et al. 2016). Climate change will impact the remaining mangroves in Kenya, through sea-level rise, aridity, and sedimentation (Kairo and Bosire 2016).

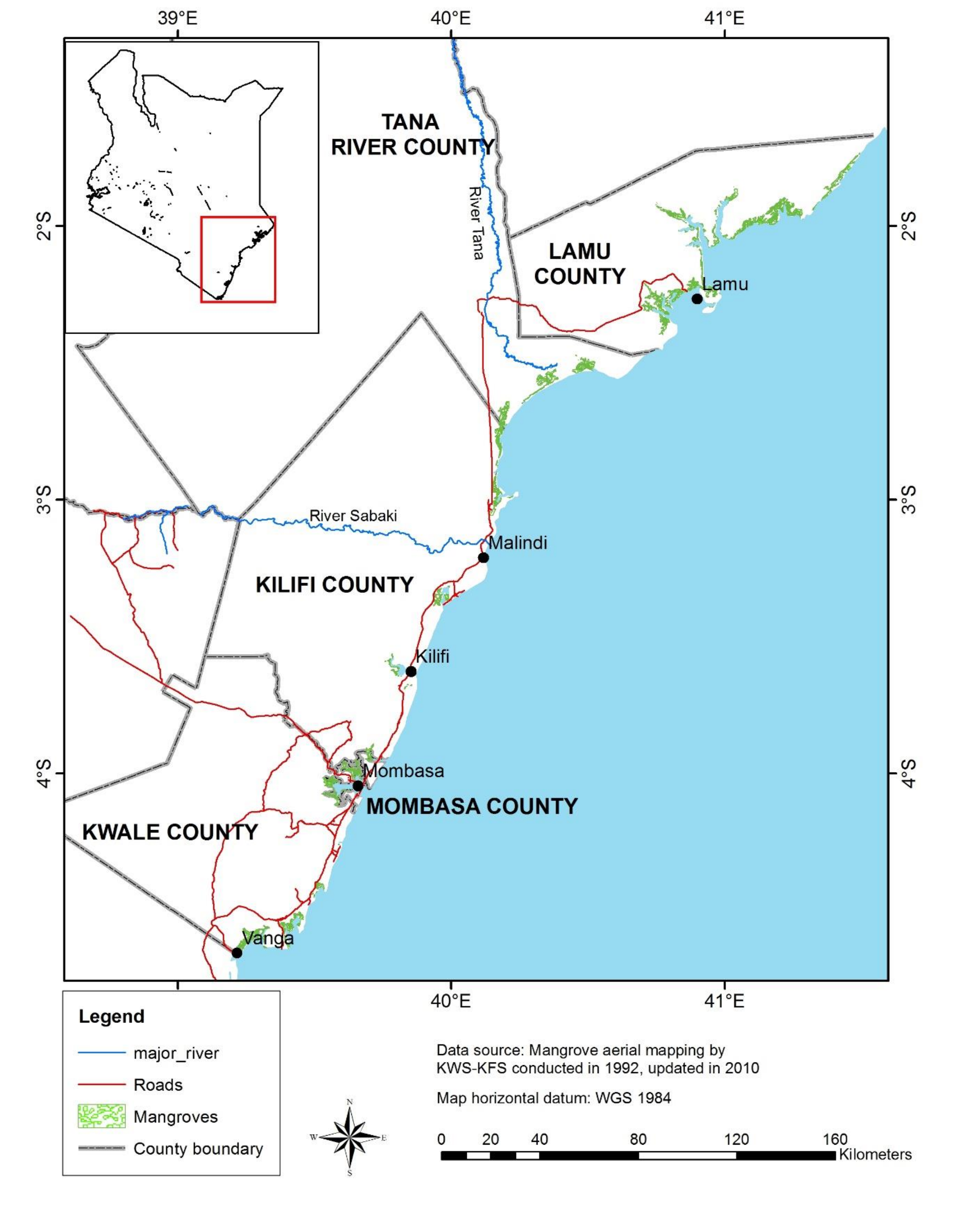

Figure 1.1: The Kenya coastline showing major mangrove areas in Lamu, Tana River, Kilifi, Mombasa, and Kwale counties

Mangroves in Kenya were gazetted as government reserve forests in 1932 (Bosire et al. 2016). The management of mangroves is vested with the Kenya Forest Service (KFS), and in partnership with Kenya Wildlife Service (KWS) whenever they occur within marine protected areas (MPA). The Forest Conservation and Management Act 2016, provides for the establishment, development and sustainable management, conservation, and utilisation of forest resources for socio-economic development of the country and environment sustainability. Part V sections 48 allow for community participation in the conservation and management of public forests through a Community Forest Association (CFA) and the signing of a Forest Management Agreement. Several CFAs have been established along the Kenyan Coast through which communities can participate in the protection and conservation of the mangrove forest (GoK 2017).

The Government of Kenya has developed National Mangrove Ecosystem Management Plan (2017 – 2027) to enhance the sustainable management of mangrove forests. The Participatory Forest Management (PFM) approach is also geared to promote co-management of forest resources by Kenya Forest Services (KFS). KFS is mandated with a licensing procedure to control mangrove harvesting. But this strategy is based on demand for products rather than the actual status of resources (Abuodha and Kairo, 2001). KFS has the mandate to introduce a periodic ban on mangrove logging to regulate the removal of wood products hence allowing for the regrowth of the forest. The first ban was imposed in 1982 on the export of mangrove poles from Lamu county (Idha 1998; Taylor et al. 2003). National bans to reduce the loss and degradation of mangroves were executed in 1997 (GoK 2017) and 2018. The 2018 national ban is still in place except for Lamu county where it was lifted in 2019 after petitions and community outcry due to the impact on the local economy. To date, Lamu communities still rely on the use of mangrove poles for construction, despite some use of other materials (e.g. steel and concrete building blocks).

About 61% of mangroves in Kenya occur in Lamu county, where current threats include illegal harvesting of mangrove wood for use in traditional lime making and construction (GoK 2017) and infrastructure development (Kairo and Bosire 2016). Large-scale infrastructure projects in Lamu include the Lamu Port and Southern Sudan Ethiopian Transport (LAPPSET). The research presented in Chapters 3 to 5 focuses on Lamu county due to its extensive mangrove coverage (GoK 2017) and the importance of mangroves to coastal communities in Lamu county (Idha 1998).

1.6 Aim and objectives

This study aimed to elaborate an evidence-based coastal adaptation framework for mangrove-dependent communities informed by a better understanding of how coastal communities in Kenya have perceived and responded to changes in mangroves. The study has four main objectives:

1. To understand mangrove utilisation around the world through a systematic review of the literature (Chapter 2).
2. To assess the local perception of the status and uses of mangroves in Lamu county using a questionnaire survey (Chapter 3).
3. To analyse changes in mangroves in Kenya using global and national databases and the implications for coastal protection using the Integrated Valuation for Ecosystem Services and Tradeoffs (InVEST) coastal vulnerability model (Chapter 4).
4. To develop a coastal adaptation framework to assist coastal communities and government agencies to implement more sustainable practices and management (Chapter 5).

1.7 Thesis structure

This thesis uses a mixed-method approach, which includes a systematic literature review, a questionnaire survey, participatory consultation tools, land use and land cover change analysis, and modelling (Figure 1.2). The use of multi-methods allows for a comprehensive understanding of the research problem through data triangulation, which limits bias associated with any single method (Creswell and Plano Clark 2018). Each method and the resulting findings are covered in Chapters **2-5**, each containing a chapter-specific Introduction providing the context of the topics covered in the chapter, Methods, Results, Discussion and Conclusions. **Chapter 6** is the concluding chapter which brings together the key findings, highlighting how they, combined, advance the current knowledge and practices, and identify directions for future research.

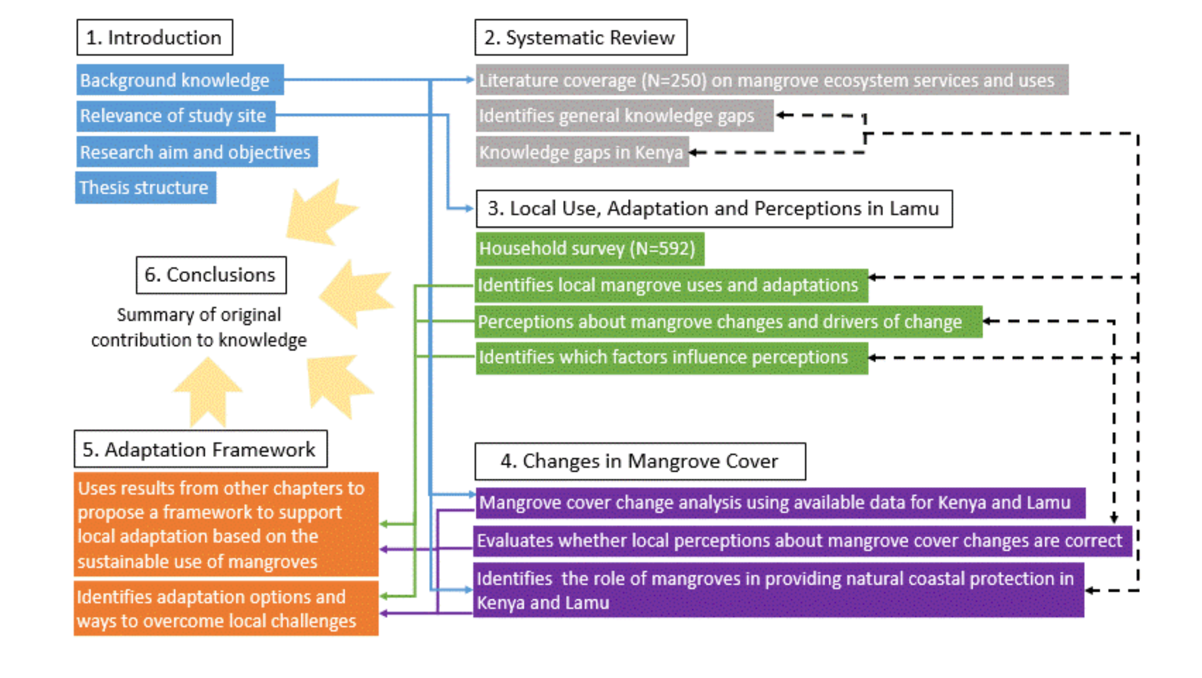

Figure 1.2: Summary of the thesis structure, showing information on the content and methods applied in each chapter and their linkages

Chapter 2 establishes the current knowledge on mangrove ecosystem services and utilisation of mangrove resources around the world following a systematic literature review on the Web of Science. Findings from this chapter form the basis of knowledge on mangrove goods and services employed in Chapters 3 and 4.

Chapter 3 investigates the use of mangroves by the local communities and their perception of changes happening in the mangrove forests and their adaptation experiences through a questionnaire survey with 592 respondents from five locations in Lamu county. This major survey effort provides new evidence of how experiences and perceptions differ geographically and across respondents' socio-demographic characteristics. The information obtained underpins the development of a framework to support adaptation strategies at the local level (Chapter 5).

Chapter 4 provides an analysis of changes in the extent of mangroves in Kenya and Lamu county between 1990 and 2019 using national and global data. Using the InVEST coastal vulnerability model, the implication of these changes to the provision of ecosystem services, focusing on coastal protection, is analysed and compared with the role of other coastal habitats (corals reef and seagrasses). The InVEST coastal vulnerability model was used to identify the contribution of mangrove forests in reducing exposure of the coastline to coastal hazards compared to that of coral reefs and seagrass ecosystems.

Chapter 5 presents the co-creation of a framework that offers practical guidance to support local adaptation for the sustainable use of mangroves**.** The framework is developed through an analysis of stakeholders' consultation feedback regarding adaptation options employed by mangrove-dependent communities along the Kenyan coast. The chapter provides long-term adaptation options while creating opportunities for mangrove-dependent communities to cope with changes happening in the mangrove forests.

2 Mangrove ecosystem services and utilisation of resources: a systematic review

2.1 Introduction

The concept of ecosystem services dates from the 1970s (de Groot et al. 2010; Costanza et al. 2017), but efforts to put the concept into practice gained momentum after the categorisation of ecosystem services by the Millennium Ecosystem Assessment (de Groot et al. 2010) (see Chapter 1). It has created an effective bridge between ecological and economic approaches, challenging the established views about the 'value' of nature and the long-lasting and wider economic impacts of nature degradation (Costanza et al. 2017). The recognition of use and non-use values emerged (de Groot et al. 2010). Regarding mangroves, the use value includes both the direct resources obtained e.g., the products (wood, fish, tannin) and indirect services such as erosion prevention. The non-use values are the importance attributed to an aspect of the environment or the value of its existence (de Groot et al. 2010). The geographical and cultural variation of ecosystem services value has necessitated the need to gather and integrate information on ecosystem services with the goal of learning, adapting and better informing policy (Costanza et al. 2017).

A systematic review involves comprehensively identifying all relevant existing knowledge on a specific topic to answer a particular question or to direct future research efforts by addressing knowledge gaps (Petticrew and Roberts 2006). The key aspect of a systematic review is the transparency and quantitative aspect of the method that would allow others to follow the same procedure and reach the same number of papers (Følstad and Kvale 2018). This method has been extensively used in health science (Petticrew 2001) and is increasingly used to establish the current knowledge in environmental studies. Relevant to this research, systematic reviews covered valuation studies on blue forests (Himes-Cornell et al. 2018), ecosystem services of marine and coastal systems (Liquete et al. 2013) and the effect of land use land cover changes on mangroves ecosystem services (Sasmito et al. 2019).

As changes in mangrove forests are mostly linked to mangrove use (Sasmito et al. 2019; Goldberg et al. 2020), it is important to understand how the use of mangroves has globally evolved, while identifying the impact of use on the provision of ecosystem services. Hence, a systematic review of the scientific literature aimed to identify the current understanding of geographical differences in mangrove use globally to better assess commonalities and particularities of mangrove utilisation in Kenya. To achieve the aim, the following specific objectives were addressed:

1. establish the current knowledge about mangrove use through a systematic analysis of the scientific literature;
2. identify global patterns of mangrove resource use; and
3. ascertain the differences in mangrove use around the globe to that of Kenya.

2.2 Methods

A systematic review was undertaken following the methods of studies such as that of Berrang-Ford et al. (2011) and Xu et al. (2019). The search was conducted (January 2020) in the Web of Science (WoS) . This database is the most used search engine, covers interdisciplinary peer-reviewed literature and includes literature published since 1900 (Jacsó 2005). The search criteria were:

Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI

Timespan=All years (1900 to December 2019)

Language: English

Document types: Article OR Book Chapter OR Proceedings Paper OR Review

Topic search (TS) within the title, author keywords, Keywords Plus® or abstract:

1. TS= (Mangrove* NEAR use*) OR
2. TS= (Mangrove* NEAR Valu*); OR
3. TS= (Mangrove* NEAR Utili*).

   The function NEAR finds records containing all terms within 25 words of each other, maximising the chances of finding relevant literature.

The search yielded a total of 2,738 articles. The titles, authors' keywords and the abstracts of the 2,738 articles were exported to EXCEL. An additional keyword search was done on the EXCEL file to identify which papers mention the different services (using the condition formatting function and exporting to a different EXCEL sheet). Table 2.1 shows the outcomes of the search and exclusions after the screening of the titles and abstracts.

Table 2.1: The number of articles found in the search and excluded during the review process per type of ecosystem service

EXCEL keywords	**Number of articles found**	**Excluded after screening**	**Included after screening**	**Inclusion after re-categorisation**	**Number of Articles analysed**
Fisheries	133	78	55	49	104
Habitat	649	597	54	3	57
Carbon sequestration and storage	72	31	41	5	46
Fuel and cooking	71	40	31	15	46
Construction	107	92	14	23	37
Coastal protection	51	32	19	6	25
Tourism and recreation	84	64	20	0	20
Food and Feed	342	336	6	12	18
Medicine	45	32	13	4	17
Tannin and dye	41	29	12	4	16
Waste management and water purification	6	3	3	4	7

If screening identifies that the paper mentioned one service, but the focus was on another, the paper was moved to the relevant category. A total of 250 articles were retained for full-text reading and extraction of information. Excluded articles were covering habitat complexity, remote sensing and mangrove mapping, experimental/isotope analysis, analysis of the physicochemical composition, genetics studies, or other studies not focusing on mangrove use or ecosystem services (Appendix I- providing justification of excluded articles).

2.3 Results

The search identified articles published from 1993 to 2019. The number of publications increased over time, with the highest numbers published in 2018 (19%) and 2019 (16%) (Figure 2.1).

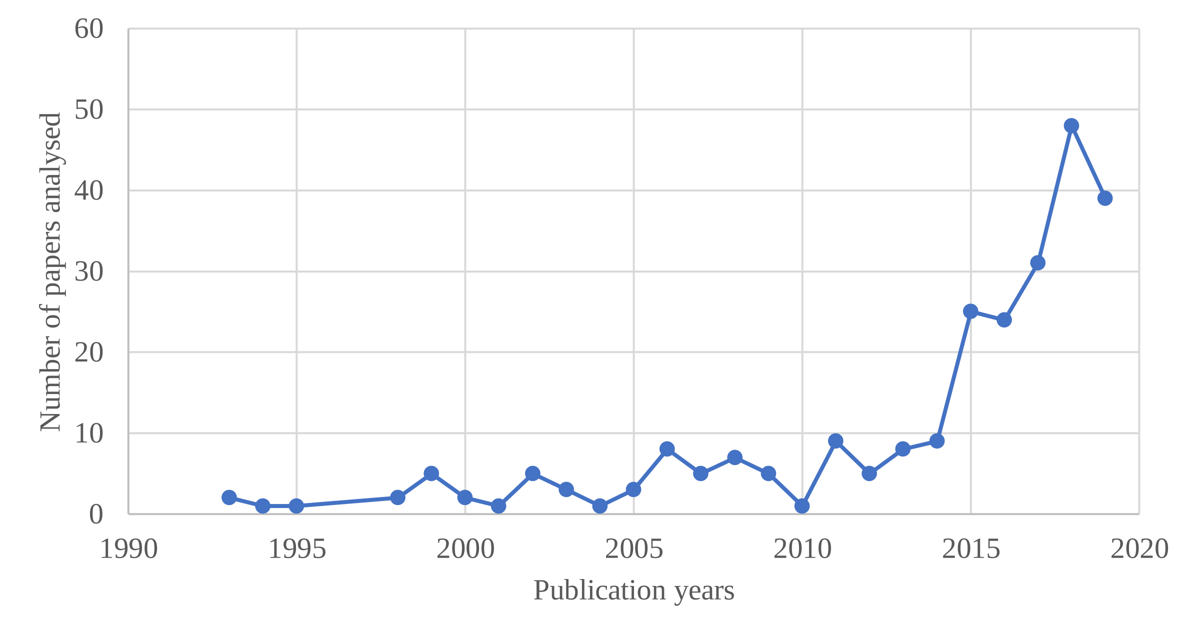

Figure 2.1: Number of papers analysed per year of publication

The articles have captured 11 mangrove ecosystem services including wood for construction and fuel, provision of food and fodder, tanning/dye, and medicines for different ailments (Figure 2.2). The role of mangroves in supporting fisheries is the most often mentioned topic, covered in 42es% (104) of the papers, followed by the provision of habitat, covered in 23% of the papers (Figure 2.2). Mangroves' provision of coastal protection (relevant to Chapter 4) is mentioned in only 10% of the papers. Preferences for particular species for a particular use is observed worldwide e.g., in North America (Kovacs 1999; Cornejo et al. 2005), South America (Palacios and Cantera 2017), Africa (Dahdouh-Guebas et al. 2000; Traynor and Hill 2008; Jiazet and Hans 2019), and in Asia (Walters 2005a; Dahdouh-Guebas et al. 2006; Hussain and Badola 2010; Furukawa et al. 2015).

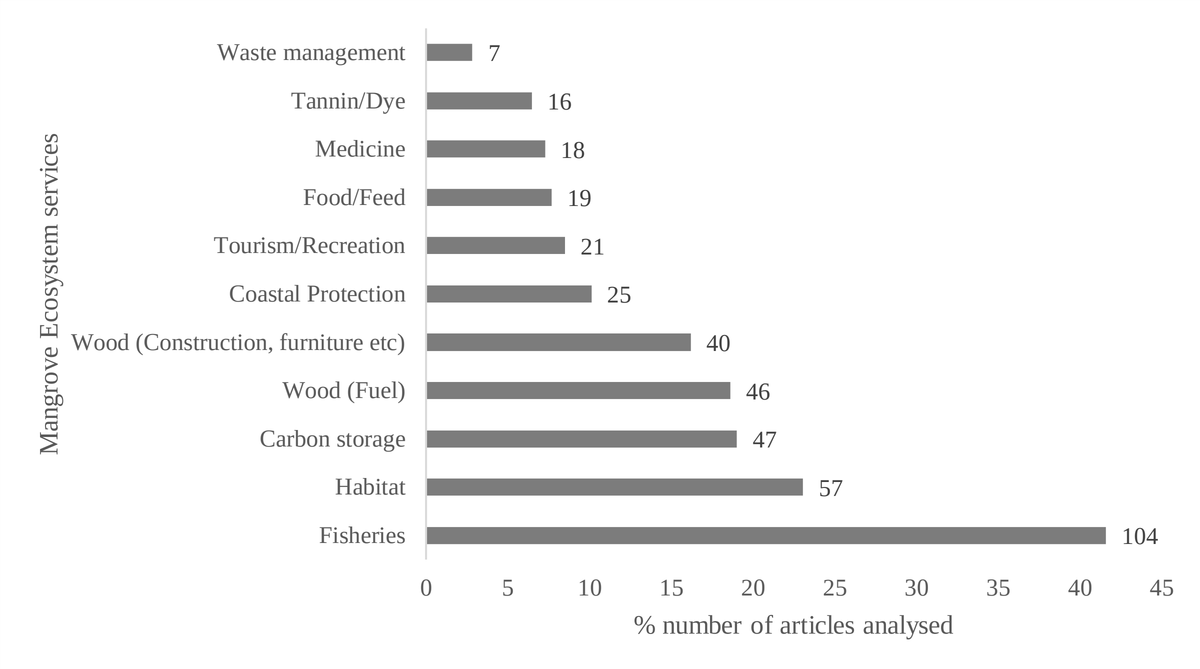

Figure 2.2: Ecosystem services covered in the 250 articles analysed

Papers focusing on mangrove use and ecosystem services in Asia dominate (43% of all papers). This region is also the most covered in all ecosystem services (Figure 2.3).

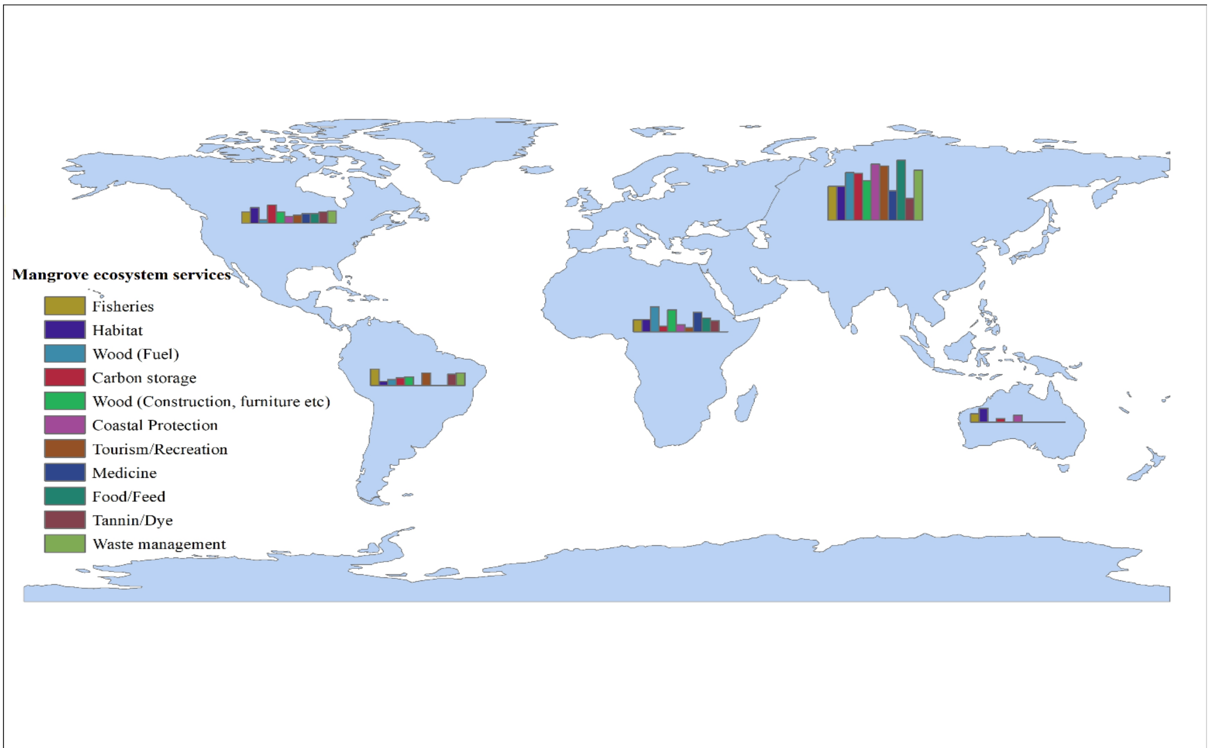

Figure 2.3: Coverage of ecosystem services by region

Services that were covered in all the regions include the contribution to fisheries, provision for habitat and carbon storage. The coastal protection service was captured in papers from all regions except South America. Uses of mangrove wood for construction and fuel, tourism/recreation and tannin/dye were represented in all continents except in Oceania. Articles on mangrove ecosystem services on a global scale (8% of the articles, n=21) presented good coverage on the use of mangroves for tannin/dye (38%) and medicine (33%) (Figure 2.4).

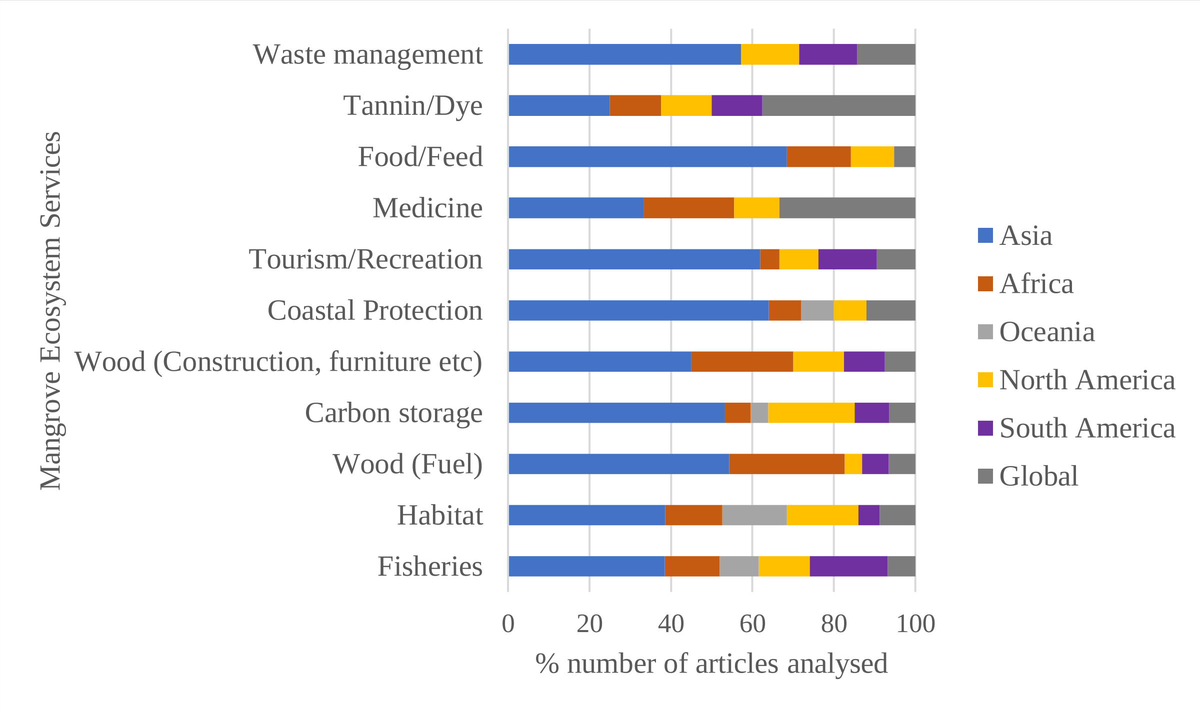

Figure 2.4: Distribution of articles analysed across the world

The next subsections will summarise the findings from the content analysis of the literature. Section 2.3.1 focuses on the knowledge related to each ecosystem service while section 2.3.2 analyses the geographical coverage of mangrove utilisation.

2.3.1 Overview of ecosystem services

This section provides a discussion on ecosystem services covered in literature which include fisheries support, habitat, carbon sequestration, wood for construction, Coastal protection, recreation, food and/or feed, tannin, medicine, and waste management.

Fisheries support

The provision of nursery areas and habitats for commercial and endangered fish species is widely recognised in the literature as a key contribution of mangroves to fisheries (Barbier and Strand 1998; Barbier 2000; Blaber 2007; Gajdzik et al. 2014; Adams and Murchie 2015; Tsai et al. 2015; Azevedo et al. 2016; Abdullah-Al-Mamun et al. 2017; Morgan et al. 2017; Nagelkerken et al. 2017; Das 2017; da Silva et al. 2018; Keur et al. 2019; Lee et al. 2019; Carrasquilla-Henao et al. 2019). Mangroves are important habitats for many coastal and marine species (Veettil et al. 2019; Du et al. 2020). For example, juvenile rays and sharks use mangroves as a refuge from predators (Davy et al. 2015; Escalle et al. 2015; Harborne et al. 2016; Stump et al. 2017; Dubuc et al. 2019; Kanno et al. 2019). The interconnections between mangroves and other coastal ecosystems (e.g., seagrass, tidal marshes and coral reefs) play a critical role for the many species that seek shelter or spend part of their life cycles in mangroves (Meynell 1999; Lugendo et al. 2006; Crona and Ronnback 2007; Meynecke et al. 2008; Unsworth et al. 2009; Vila-Nova et al. 2011; Kimirei et al. 2011; Berkström et al. 2012; Vaslet et al. 2015; Hylkema et al. 2015; Oliveira et al. 2016; Shahraki et al. 2016; Muller and Strydom 2017; Skilleter et al. 2017; Vane et al. 2018; García-Rivas et al. 2018; Le et al. 2018; Abrantes et al. 2019; Sambrook et al. 2019; Jänes et al. 2020). The presence of mangroves in the intertidal area has been proven important in increasing the diversity and abundance of fish assemblages in the nearshore coral reefs, as seen in the Caribbean (Serafy et al. 2015).

Higher species richness and abundance are found around mangrove roots, as they offer effective shelter against predators, influencing the distribution of small fishes (Nanjo et al. 2014). A large diversity of mangrove-related fish is found in the Indo-west pacific to the central pacific with over 600 species recorded (Blaber 2007). Large forests with long mangrove-river interfaces and numerous creeks provide suitable nursery habitats for fish (fish families of Lutjanidae, Haemulidae, and Serranidae) and shrimps (Blaber 2007; Chong 2007; Jamizan and Chong 2017). Due to their high productivity, mangroves are also important feeding grounds (Abrantes et al. 2015) for most fish (Lugendo et al. 2006; Peng et al. 2017) and turtles (Denton et al. 2016). The abundance and diversity have been seen to fluctuate with tidal cycles (Dumas 2006; Castellanos-Galindo and Krumme 2015; Reis-Filho et al. 2016; Shahraki et al. 2016; Pülmanns et al. 2018) e.g., high abundance of juvenile fish observed during neap tide at night and lowest during the daytime in spring tides. Natural mangroves in Florida showed higher abundance but lower species richness than restored mangroves (Peters et al. 2015). This result indicates the effect of habitat structure and the potential of mangrove restoration to increase biodiversity.

Besides the nursery and feeding grounds that are vital to the maintenance of fisheries, mangroves are directly used as fishing areas (Barbier and Strand 1998; Walters et al. 2008; Hutchison et al. 2015; Taylor et al. 2018; Carrasquilla-Henao et al. 2019; Jänes et al. 2020) and they also support aquaculture development (Rönnbäck 1999). Local communities' dependence on mangroves for fish and molluscs collection is documented in many developing countries worldwide; with evidence from Bangladesh (Uddin et al. 2013; Rahman et al. 2018; Barua and Rahman 2019), India (Rönnbäck et al. 2003; Dahdouh-Guebas et al. 2006; Hussain and Badola 2010; Anneboina and Kavi Kumar 2017), Indonesia (Suharti et al. 2016; Perdana et al. 2018; Purida and Patria 2019; Rumahorbo et al. 2019), Vietnam (Quoc Vo et al. 2015; Veettil et al. 2019), Sri Lanka (Satyanarayana et al. 2013), the Philippines (Walton et al. 2006; Samonte-Tan et al. 2007), Thailand (Barbier 2005; Islam and Ikejima 2009), Malaysia (Bennett and Reynolds 1993), Brazil (Ron and Padilla 1999; Barletta-Bergan et al. 2002; Glaser 2003; Saint-Paul 2006; Moreira dos Santos and Lana 2017; Zapelini et al. 2017), Myanmar (Feurer et al. 2018), Martinique (Failler et al. 2015), Belize (Arkema et al. 2015), Ecuador (Beitl 2017; Tanner et al. 2019), Fiji (O'Garra 2012; Atkinson et al. 2016), Senegal (Conchedda et al. 2011), Ghana (Nortey et al. 2016), Kenya (Abuodha and Kairo 2001; Huxham et al. 2015), and regional studies in West Africa (Carney 2017) and Eastern Africa (Semesi 1998).

Being a suitable environment for fish, mangrove areas have been converted to shrimp farming, a problem that is widespread in Asia. Nickerson (1999) assesses the socio-economic trade-offs of aquaculture development in mangrove areas in the Philippines. Results suggest that undeveloped mangrove areas provide a higher net benefit than polyculture or semi-intensive aquaculture (Primavera 1995; Nickerson 1999), which justifies the conservation and rehabilitation of the remaining mangrove forest. The loss of mangroves has a strong impact on the economy of fishing coastal communities. Degraded mangrove forests are shown to have low fish diversity and abundance (Tran and Fischer 2017). The fish catch was reported to increase with mangrove abundance and decrease in degraded mangrove areas in India (Das 2017), Bangladesh (Islam and Haque 2004), Myanmar (Estoque et al. 2018), Thailand (Barbier et al. 2002; Barbier 2005; Premcharoen et al. 2016), California (Aburto-Oropeza et al. 2008), and Mexico (Carrasquilla-Henao et al. 2013). Mangroves are used as nurseries or feeding areas for commercial and threatened reef species (fish from the families Epinephelidae, Lutjanidae, Carangidae, Carcharhinidae, Rhinobatidae and Sphyrnidae). Therefore, to manage anthropogenic impacts on fisheries and coral reefs there is a need to consider broader scales hence calling for the protection of estuaries (Vila-Nova et al. 2011; Sambrook et al. 2019).

Habitat

In addition to marine species, mangroves provide habitat for other fauna (Eong 1993), including birds, mammals, reptiles, and amphibians (Bennett and Reynolds 1993; Abdullah-Al-Mamun et al. 2017; Rog et al. 2017; Dencer-Brown et al. 2018), including endangered or threatened species. In Madagascar, over 20% of the lemur species use mangroves for foraging, sleeping, and travelling between terrestrial patches (Gardner 2016). Bengal tigers live in the Sundarbans of India and Bangladesh and, in India, part of it was declared a Sundarbans Tiger Reserve (Naha et al. 2016). Mangroves are particularly important for the conservation of these iconic mammals, as the IUCN Red List of Threatened Species (2020) includes 98% of all lemur species in Madagascar as threatened and 31% as Critically Endangered, the Bengal Tiger is listed as a threatened species since 2010.

Mangroves are important for the life cycle of local and migratory birds (semipalmated plover, spotted sandpiper, and white-rumped sandpiper) (some endangered) around the world (Ruiz et al. 2017; Mancini et al. 2018). The avifauna (both terrestrial and waterbirds) utilises the mangrove forests for feeding, breeding, and roosting. A study conducted in different mangrove areas in Brazil noted that more terrestrial birds (e.g., pigeons, doves, vultures, and house sparrow) visit the mangrove areas than aquatic birds (e.g., South American tern, royal Tern, black-crowned night heron and scarlet ibis)(Mancini et al. 2018). Another study conducted in Mexico noted the contribution of mangroves to seven trophic guilds (granivores and frugivores, insectivores, carnivores, herbivores, insectivores, generalists and piscivores) of 139 species of birds (Ruiz et al. 2017).

Mangrove-bird connectivity is primarily limited by the interaction between bird behaviour, bird resource requirements and the types of habitats available in surrounding areas (Buelow and Sheaves 2015). The diversity of bird species differs between areas due to habitat heterogeneity. Mancini et al. (2018) in their study investigating bird diversity in different habitats in Brazil, observed a higher abundance in large mangrove sites and in areas with greater edge vegetation which provide different niches for birds. The importance of mangrove areas for courtships, insect feeding, and protection from weather and night for numerous bird species was identified in Mexico (Ruiz et al. 2017; Ruiz et al. 2019), Madagascar (Gardner et al. 2017), China (Wang et al. 2017), Costa Rica (Leavelle et al. 2015), Brazil (Mancini et al. 2018), Indonesia (Hernowo 2016; Suharti et al. 2016; Budiman et al. 2019), Australia (Mohd-Azlan et al. 2014), Florida (Calle et al. 2018). The importance of understanding bird linkages to support the conservation of mangrove habitat and preserve connectivity is emphasized (Buelow and Sheaves 2015).

Molluscs form a major part of the mangrove faunal communities (Kantharajan et al. 2017). Studies have shown that mollusc assemblage is positively correlated with changes in vegetation such as forest cover, above-ground biomass, and sediment characteristics (Sen et al. 2014; Salmo et al. 2017). Seasonal variations in feeding habits of different gastropods who feed on mangrove leaves and brown algae are observed and occasionally consume diatoms and bacteria (Chen et al. 2017). Mangroves macrobenthos are used as ecological indicators as they are sensitive to changes (Gong et al. 2019). Crab burrows e.g., *Sylla serrata* provide conducive environments for other organisms. A study conducted in South Africa identified the use of these burrows by juvenile gobies *Redigobius dewaali* for forage (Kramer et al. 2015). Similarly, marine bivalves (Teredinid) tunnel mangrove woods which are used by other terrestrial and marine organisms such as centipedes, spiders, crickets, fish, octopus, and polychaetes to avoid desiccation by escaping hot temperatures (Hendy et al. 2014).

Mangroves host bacteria communities (Li et al. 2018; Rampadarath et al. 2018) and ants (Jin et al. 2019) that contribute to the functioning and maintenance of the ecosystem. Bacteria communities show seasonal fluctuation in diversity and abundance as well as distinct differences in sediment depths and geographic locations as observed in a study in China (Li et al. 2018) and Mauritius (Rampadarath et al. 2018). Differences are also observed in pristine and anthropogenically influenced mangrove ecosystems in Saudi Arabia by the Red Sea (Ullah et al. 2017).

Carbon sequestration and storage

In recent years, many studies focus on the quantification of carbon sequestration to assess the importance of mangrove forests as a carbon sink or the impact of deforestation on carbon storage mostly at a local scale (Failler et al. 2015; Barreto et al. 2016; Dung et al. 2016; Jerath et al. 2016; Benson et al. 2017; Howard et al. 2017; Arshad et al. 2018; Asadi et al. 2018; Sanderman et al. 2018; Sidik et al. 2018; Xiong et al. 2018; Tanner et al. 2019; Kusumaningtyas et al. 2019; Rumahorbo et al. 2019). Such quantifications are needed to provide evidence of carbon sequestration potential for management and conservation purposes as well as to reduce emissions from deforestation and degradation (REDD+) (Chen et al. 2012; Dung et al. 2016; Jacotot et al. 2018; Sanderman et al. 2018; Cameron et al. 2019; Feng et al. 2019).

Mangrove forests are an important carbon sink of anthropogenic greenhouse gas emissions (Eong 1993). Mangroves are shown to have higher carbon content than other coastal blue carbon, such as salt marshes (Bianchi et al. 2013; Yando et al. 2016; Radabaugh et al. 2018). For example, mangroves soils are reported to sequester 253 to 270 g C m^{-2} yr^{-1}, more than double the 101-125 g C m^{-2} yr^{-1} sequestered by salt marshes sediments in Mexico (Bianchi et al. 2013). Similarly, studies from China (Cui et al. 2018) and Florida (Jerath et al. 2016) show that mangroves sequester more carbon than nearby terrestrial forests.

Mangroves store a large amount of organic carbon (e.g., 211 Mg C ha^{-1} in Galapagos to 1,269 tonnes ha^{-1} in Indonesia), the majority of which is found below ground in the sediments (Abdullah-Al-Mamun et al. 2017; Purida and Patria 2019; Tanner et al. 2019). Despite several studies on carbon storage capacity by mangroves around the world, the quantification has been undervalued in most areas. The below-ground soil carbon represents the highest carbon pool as seen in most studies (Zhang et al. 2013; Guerra-Santos et al. 2014; Alongi et al. 2016; Bhomia et al. 2016; Chen et al. 2018) has been unquantified/unknown in most areas in Vietnam (Quoc Vo et al. 2015; Warner et al. 2016), and Indonesia (Alongi et al. 2016). Adequate quantification of below and above-ground carbon storage is important to provide scientific evidence to finance mangrove conservation efforts.

Differences in magnitude and the rate of carbon storage are observed when comparing sites (Atkinson et al. 2016; Barreto et al. 2016; Costa et al. 2019; Kusumaningtyas et al. 2019; Ochoa-Gómez et al. 2019). The variation in magnitude and rate of storage differs with the structure of the forest (Kauffman et al. 2014; Hemati et al. 2015; Bhomia et al. 2016). Bhomia et al. (2016) noted different C stocks for different forest structures, where low, medium, and tall mangroves have 1200, 800 and 900 Mg C ha^{-1} respectively. Different species contribute differently to the C sink (Guerra-Santos et al. 2014; Barreto et al. 2016; Hilmi et al. 2017; de Ramos et al. 2019; Hadi et al. 2019) and the carbon sink capacity has been noted to decline with ecosystem age (Walcker et al. 2018; Sahu and Kathiresan 2019). In addition, forests with mixed species of mangroves sequester more carbon than mono-species hence a better option for mangrove restoration (Chen et al. 2012). The carbon storage from disturbed mangrove forests is noted to be lower than that of undisturbed forests (Dung et al. 2016). Also of importance is that encroachment of mangroves into salt marshes and unvegetated mudflats leads to increase carbon storage and that could in the future reverse global warming (Doughty et al. 2016; Feng et al. 2019).

Wood for construction and other uses

Wood was most cited to be used in construction and for fuel. Uses of mangrove forest wood have been observed as an ancient activity for the local communities living along the coast in the tropical and subtropical regions (Satyanarayana et al. 2012; Huxham et al. 2015; Kusmana 2018; Teka et al. 2019). The study identified the global use of wood products for house construction (Abuodha and Kairo 2001; Walters 2005a; Hussain and Badola 2010; Conchedda et al. 2011; Failler et al. 2015; Scales et al. 2018) and fishing gears such as fish traps, paddles, boats (Bennett and Reynolds 1993; Cornejo et al. 2005; Saint-Paul 2006; Rönnbäck et al. 2007; Pattanaik et al. 2008). The quality of the wood (Walters et al. 2008) and its resistance to salinity and termite attacks (Conchedda et al. 2011) make it durable and well-sought for construction. Other uses for wood include furniture making, transmission, telephone poles, railway girders, and mine timbers (Walters et al. 2008; Arunprasath and Gomathinayagam 2015). The systematic review identified changes in the use of mangrove wood due to the observed impact on mangrove forests. The extraction of mangrove wood for construction is limited to domestic consumption and local and regional markets (Walters et al. 2008).

Mangrove wood is widely preferred for fuel because it is more durable, has fast heating, and has less smoke (Suharti et al. 2016). A study conducted in Indonesia showed *Bruguiera gymnorrhiza* to have a higher calorific value (de Ramos et al. 2019) than *Rhizophora mucronata*, *Ceriops tagal*, and *Sonneratia spp.,* hence preferred by locals for fuelwood because of durability and ease of ignition (Pattanaik et al. 2008, Uddin et al. 2013, Furukawa et al. 2015, Palacios and Cantera 2017, Scales et al. 2018). The commercial harvesting of mangrove wood for fuel has mostly been linked to the degradation of mangroves (Feka and Manzano 2008; Winarno et al. 2016; Estoque et al. 2018).

Coastal protection

Mangroves trap sediments and reduce wave energy contributing to shoreline stabilisation (Othman 1994; Barbier et al. 2011), acting as natural barriers against the impact of storms and protecting lives and property (Walters et al. 2008). In the Philippines, the absence of mangroves is likely to increase flooding and damage to people and infrastructure by 25% every year (Menéndez et al. 2018). Coastal protection has been identified as the main indirect benefit of mangroves and the major reason for planting mangroves on low-lying coasts (Walters et al. 2008). The protection capabilities of mangroves are dependent on the quality of the habitat (including the biomass, morphology, and structural complexity), determining the wave attenuation capacity, sediment accretion and erosion prevention (Quang Bao 2011; Arkema et al. 2015; Doughty et al. 2017). Studies have shown that the height of the wave is closely related to the cross-shore distance of mangrove coverage, as wave height is reduced with the increased width of the forest (Quang Bao 2011; Doughty et al. 2017). Degraded mangrove areas are less able to protect the coastline than undegraded sites (Estoque et al. 2018).

Mangroves and other blue carbon ecosystems (seagrasses and salt marshes) play a key role in protecting the coastline against erosion. A study in East Central Florida demonstrated that mangroves were found to attenuate waves of different wave heights over a significantly shorter distance compared to salt marshes (Doughty et al. 2017). The study which modelled the protection service using InVEST noted that mangroves prevented 470% more erosion than salt marsh habitats (Doughty et al. 2017) due to the sheer strength offered by the volume and structure of the below-ground roots (Barbier et al. 2011).

Mangrove valuation studies show that coastal protection is an indirect service having a higher value than direct use services, such as wood (Sanford 2009; Estoque et al. 2018; Putranto et al. 2018). In South-Eastern China, the coastal protection value for mangroves was 83% of the total ecosystem services (Wang et al. 2018). The economic valuation of mangrove forests in the articles analysed here was based on two methods, damage avoided and replacement costs, with the latter being used more often (Sanford 2009; Barbier et al. 2011; Rao et al. 2015; Atkinson et al. 2016; Estoque et al. 2018; Wang et al. 2018; Rumahorbo et al. 2019). Valuation studies aim to influence conservation planning and restoration of this critical habitat. Valuation conducted at a local scale using the replacement coast method estimated the protection function of mangroves in Youtefe Bay at US$ 1.3M yr^{-1} (Rumahorbo et al. 2019) and in Banggai US$1.14M $year^{-1}$ (Putranto et al. 2018) both in Indonesia and at US$ 239,683 yr^{-1} in South-Eastern China. On a national scale, the value of the coastal protection service was US$ 433,840 to US$ 30,073 yr^{-1} in Fiji (Atkinson et al. 2016). A national-wide evaluation in the Philippines costs mangroves US$1 billion yr^{-1} using the damage avoidance method (Menéndez et al. 2018). In Kenya conservative estimates of protection against erosion and extreme weather events for four coastal areas (Gazi, Vanga, Funzi and Mwache) by 2014 were US$ 2.4M yr^{-1} (Huxham et al. 2015).

Furthermore, the incidents of extreme weather events (tsunamis) in Asia have led to the appreciation of the protective function of mangroves due to evidence of protections noted and not through scientific research like the attenuation of wave energy which has been scientifically proven (Walters et al. 2008). Of most importance, analysed articles presented the recognition of the mangrove's coastal protection service against floods and extreme weather events by coastal communities in India (Dahdouh-Guebas et al. 2006), Vietnam (Quoc Vo et al. 2015; Van Cuong et al. 2015; Veettil et al. 2019), Bangladesh (Abdullah-Al-Mamun et al. 2017), the Philippines (Walton et al. 2006), Malaysia (Bennett and Reynolds 1993), Martinique (Failler et al. 2015), and Fiji (O’Garra 2012). Recognising the coastal protection service offered by mangroves, the department of irrigation and drainage in Malaysia maintained strips of mangroves to reduce wave energy and protect earth embankments that were built to protect agricultural areas (found behind mangrove areas) from tidal inundation between the 1950s to 1980s (Othman 1994).

Recreation/Tourism and other cultural services

Mangrove tourism is a leisure activity presented as soft ecotourism, a day trip combining the discovery of natural landscapes and ecosystems (Avau et al. 2011). Tourism activities in mangrove areas include sightseeing, canoeing, bird watching, visiting aquaculture sites (Fan et al. 2013), and getting involved in mangrove conservation programmes. Mangrove tourism is also linked to education and research where students and tourists pay a fee to learn about the area, as reported in Brazil (Souza and Ramos e Silva 2011). Eco-farming in mangrove areas with mariculture systems is accessed by boardwalks facilitating ecotourism and public education in China (Fan et al. 2013).

Spalding and Parrett (2019) did a global analysis on the popular travel website (TripAdvisor) and identified close to 4000 attraction sites in mangroves in 93 countries, 2/3 of which are in North America and the Caribbean. The use of boating is conducted in 82% of these sites and bird watching in 28%. Although bird watching is a more common attraction, in specific areas people visit mangroves to see other animals, such as dugongs, crocodiles, and monkeys (Spalding and Parrett 2019). The most important tourist spot in Sarawak Malaysia is adjacent to the Sarawak mangroves Forest Reserve due to its attractive scenery (Bennett and Reynolds 1993). Other Identified potential mangrove ecotourism sites include e.g., Demak District (Perdana et al. 2018) and Karimata Island (Rudiastuti et al. 2018) in Indonesia to enhance the management of the mangrove forests.

Mangrove ecotourism is a common activity around the world and motivates conservation as the local community gets economic and environmental benefits as reported in Indonesia (Basyuni et al. 2018, Kusmana 2018, Situmorang 2018) the Gambia (Satyanarayana et al. 2012) and Iran (Dehghani et al. 2010). Studies have noted that although having enormous potential for economic development, the involvement of the government in ecotourism projects is quite low (Argiati et al. 2018). Some exceptions exist, e.g., where governments explore entrance fees in areas of conservation. The Sundarbans mangroves in Bangladesh are a source of revenue for the government from both domestic and foreign tourists (Uddin et al. 2013; Abdullah-Al-Mamun et al. 2017). Yulianda et al. (2020) emphasised the need of linking mangrove ecotourism to conservation to maintain ecological processes that support the organisms, biodiversity protection and promote the welfare of the local community.

The contribution of replanted mangroves to tourism in the Philippines is evaluated at US$ 41 ha^{-1} (Walton et al. 2006) and visitors showed a willingness to pay twice the fee. The value of mangrove-based recreation in Galapagos (Ecuador) was estimated at US$16,958 ha^{-1} contributing US$ 62 million to the industry (Tanner et al. 2019). In addition to economic gains, mangrove tourism has been linked to emotional satisfaction as seen in a study conducted in Ecuador where tourists noted that they feel pleasant, and they get positive feelings when they visit such areas (Carvache-Franco et al. 2019). Aesthetic value is appreciated by locals many times referring to it being beautiful and the reason for tourists' attraction (Rönnbäck et al. 2007).

Mangrove forests are considered important for cultural services areas. They are of spiritual importance to coastal communities e.g., the Asmat community in Indonesia (Walters et al. 2008). Sacred areas such as shrines in mangroves are key areas for communities in South Coast Kenya where locals get cured from diseases and evil spirits when vising the sites (Rönnbäck et al. 2007; Huxham et al. 2015). The Sundarbans mangroves are visited by locals for spiritual aspiration (Uddin et al. 2013; Rahman et al. 2018). Thiagarajah et al. (2015) in their analysis of mangrove cultural services identified intrinsic values such as a sense of place and cultural heritage as a past value (the 1980s) and aesthetic aspects such as recreation and education being valued at present (2014). In addition, sources of recreation and education are seen increasing in the present days and spiritual/religious, sense of place and cultural heritage values decreasing in present records. Mangrove forests are noted to have served as a safe place where locals from Senegambia would go to escape slave raids and religious conversions (Carney 2017). Mangroves are also important for social activities in Indonesia, the seed of the *Xylocarpus* species is used as a toy for children (Furukawa et al. 2015).

Food and/or Feed

Mangroves are a source of food for humans and animals (Walters et al. 2008) and studies have shown that they have important nutritional values (Arefin et al. 2017; Analuddin et al. 2019). Mangrove fruits could address nutritional-related problems for malnourishment concerns of the locals - a nutritional analysis of fruits of three mangrove species (*Xylocarpus granatum, Sonneratia alba,* and *Bruguiera gymnorrhiza*) shows that the consumption of the fruits is enough to meet the daily recommended amount of sugar, protein and fats and other nutrients such as sodium and potassium for an adult (Analuddin et al. 2019). Communities also obtain proteins from shellfish such as oysters, snails, and crabs collected from mangrove areas and mostly conducted by women (Carney 2017; Rahman et al. 2018). In addition, the literature identifies the use of mangrove leaves as fodder/feed for animals in Asia, Africa, and North America.

Tannin and Dye

Mangroves are a source of many biologically active compounds including tannins (Patra and Thatoi 2011). Tannin is found in almost every plant part: bark, wood, leaves, fruits, and roots (Patra and Mohanta 2014). The genus *Avicennia* has been confirmed to contain alkaloids, flavonoids, phenols, saponins, tannins, glycosides, and terpenoids that are useful bioactive compounds (Thatoi et al. 2016). A review of the socioeconomic aspects of mangroves identifies the value of mangrove bark in producing tannin and dyes (Walters et al. 2008). Dye from mangrove bark is valued for its preservative quality and hence applied inside canoes and boats. Experimental studies conducted in Indonesia have proved that mangrove bark contains a high value of tannic compounds that could be exploited for tannins and natural colourants. *Ceriops tagal* has the highest lignin, cellulose, hemicellulose, phenolic, and tannin contents, which can be used as a raw material source for biomass and bioactive compounds (de Ramos et al. 2019), *Bruguiera gymnorrhiza* followed in high tannin content. *Rhizophora mucronata* has tannins of up to 70% responsible for its medicinal properties (Bibi, et al. 2019).

Medicines

Mangroves have been traditionally used for pharmacological activities due to their antioxidant, antidiabetic, and antimicrobial properties against a broad range of microorganisms known for causing diseases (Walters et al. 2008; Patra and Mohanta 2014; Bibi et al. 2019). The genus *Avicennia* is phytochemically diverse with ethnomedicinal use and is valued for its traditional medicinal applications. The genus has unique metabolites responsible for its antimicrobial, anticancer and anti-inflammatory activities (Thatoi et al. 2016).

Waste management/water purification

Mangroves filter pollutants and maintain water quality (Failler et al. 2015; Veettil et al. 2019). In China, they are used in the treatment of waste and/or water purification (Peng et al. 2013; Wang et al. 2017). Sewage from four villages on the Island of Ximen flows through the mangrove area of Yueqing Bay in China (Wang et al. 2017). Mangroves are planted in Integrated Mangrove Aquaculture System in southern China for ponds to become self-purifying through nutrient uptake by mangroves (Peng et al. 2013). The cost of treatment of domestic sewage in South-eastern China mangrove forests was valued at US$ 25,283 in 2015 where the retention of N and P varied with the age of the mangroves (Wang et al. 2018). In the Potengi estuary in Brazil, mangrove filtration of phosphorous, nitrogen and heavy metals arising from domestic and industrial effluents was estimated at US$ 5,300,000 highlighting the economic value of mangroves to water quality (Souza and Ramos e Silva 2011).

2.3.2 Geographical utilisation of mangroves

This section provides information on mangrove utilization in Asia, North America, South America, Oceania, and Africa.

Mangrove utilisation in Asia

Asia had the highest number of articles (108 articles or 43% of the total) compared to other regions, covering all 11 ecosystem goods and services identified. Non-harvestable mangrove products were more covered in the literature (83% of papers) than harvestable products (30% of papers). The contribution to fisheries was the most cited (37%), with the rest of the ecosystem services covered in less than 25% of articles (Figure 2.5).

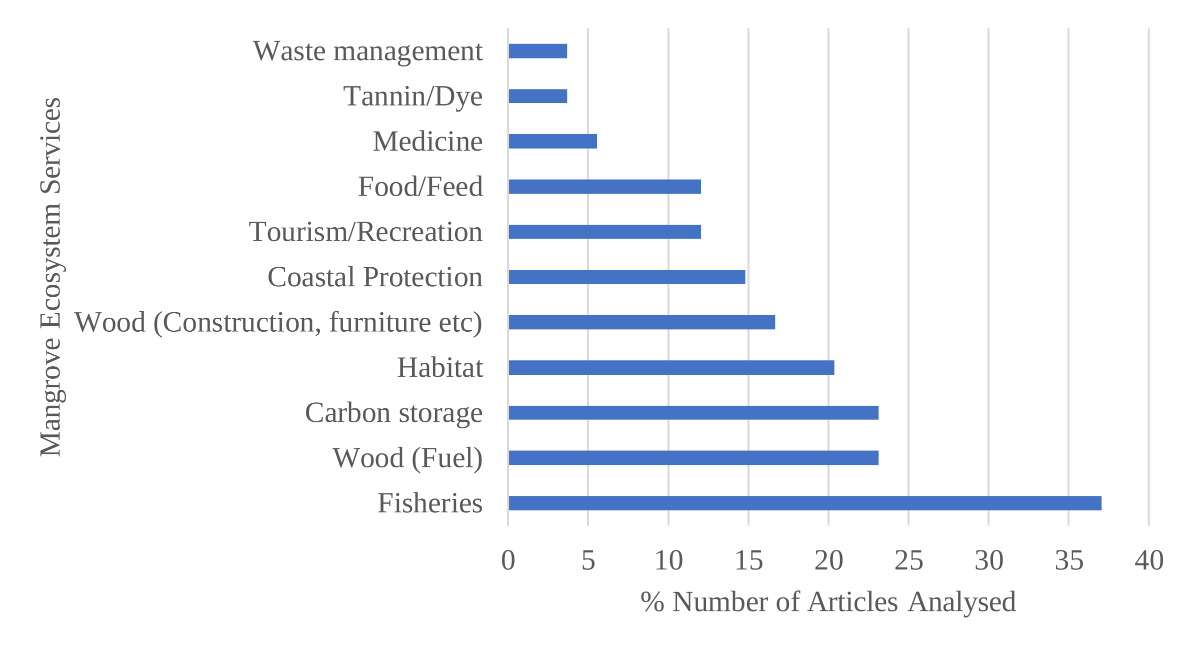

Figure 2.5: Distribution of articles analysed in Asia

Like in most regions, products harvested from mangrove forests in Asia include wood for fuel and construction and or furniture making. In the construction of houses, mangrove wood is used in various parts e.g., columns and beams as observed by the Bajo community in Indonesia (Rahim et al. 2019) and in the Philippines (Walters 2005b). Mangrove wood is also used in the making of fences in India (Dahdouh-Guebas et al. 2006), and Vietnam (Quoc Vo et al. 2015) as well as in the making of fishing gears such as fish traps, paddles, and boats in Malaysia and India (Bennett and Reynolds 1993; Pattanaik et al. 2008). The traditional use of mangrove wood as fuel by several communities in Asia was noted in literature including in India (Meynell 1999; Dahdouh-Guebas et al. 2006; Pattanaik et al. 2008; Hussain and Badola 2010), Malaysia (Bennett and Reynolds 1993), Vietnam (Quoc Vo et al. 2015; Veettil et al. 2019), Indonesia (Furukawa et al. 2015; Suharti et al. 2016; Purida and Patria 2019), Bangladesh (Arefin et al. 2017; Rahman et al. 2018) and Myanmar (Feurer et al. 2018). In some areas in Bangladesh detritus and leaves from mangroves are also used as fuel by local communities (Chow 2015; Rahman et al. 2018; Barua and Rahman 2019). Although there has been a decrease in the use of fuelwood in the Philippines (Walters 2003), consumption of fuelwood always exceeded that of house and fence construction (Walters 2005b). Other uses of mangrove wood in Asia include furniture making, transmission and telephone poles, railway girders, and mine timbers (Walters et al. 2008; Arunprasath and Gomathinayagam 2015).

The use of mangrove tannin and dye was mostly practised in Asia than in any other region. In Indonesia, the extraction of tannin from mangroves dates to 1900 with the potential to develop into an industrial activity. The tanning and dye from the bark of *Avicennia sps* are used for colouring and preserving fishing nets, colouring clothes, and used in mat making (Kusmana 2018). Like in Indonesia, extraction of tannin from the bark of mangrove (mostly *Ceriops decandra*) is a common practice in most coastal areas in India used by fishers to dye their nets and increase durability (Dahdouh-Guebas et al. 2006; Arunprasath and Gomathinayagam 2015).

The use of mangroves for medicinal values is also quite common in Asia (Arefin et al. 2017; Bibi et al. 2019; Veettil et al. 2019) Mangroves are used to treat diabetes, hypertension, and gastrointestinal disorders such as constipation, diarrhoea, dysentery, dyspepsia, haematuria, and stomach pain. Species such as *Bruguiera gymnorrhiza* and *Rhizophora mucronata* are widely used traditionally and possess several medicinal values compared to other species. In India, the fruits of *Acanthus ilicifolius* are crushed and used as a dressing for snake bites. The whole plant can be boiled in water and decoction consumed to remove kidney stones. Other uses of this species are in the treatment of asthma, diabetes, hepatitis, and rheumatism. Another medicinal species is *Xylocarpus granatum*, although poorly exploited it is used for treating cholera and diarrhoea (Bibi et al. 2019). Communities in the Sundarbans region of India have used different mangrove plants in different forms as medicine to cure some common as well as chronic ailments like fever, malaria, cold and cough, bronchitis, asthma, skin diseases, ulcers, leprosy, smallpox, diarrhoea, dysentery, diabetes, infertility (Mondal et al. 2012). The inhabitants of Bhitarkanika wildlife sanctuary, Kendrapara district in India, depend on the mangrove forests for medicine and other traditional products (Pattanaik et al. 2008). In Indonesia ointment made from *Avicennia species* is used to cure smallpox ulceration. It is also used by many as an effective contraceptive for birth control. Other medicinal uses obtained from *Ceriops* and other mangrove species include medication for toothache, used as hair treatments (prevent falling of hair), dressing for boils, curing sore eyes, tumour inhibitor, and as a mosquito repellent (Kusmana 2018).

Mangroves in Indonesia are used as food and in beverages (Kusmana 2018). The bark of *Bruguiera gymnorrhiza* and *B. parviflora* has been used for centuries in seasoning fish while the young leaves, fruits, and embryos are cooked and eaten as vegetables (Kusmana 2018). Locals in Sri Lanka make beverages from the leaves of *Sonneratia caseolaris* (Satyanarayana et al. 2013). Although reported as an activity of the past, locals in Indonesia and Bangladesh have been consuming raw seeds, leaves, and fruits of *Bruguiera cylindrica* and *B. gymnorrhiza* for sustenance (Furukawa et al. 2015; Arefin et al. 2017). The use of mangroves as vegetables is a common thing in India as well where it is cooked and eaten raw in salads with fruits of *Bruguiera gymnorrhiza*, *Sonneratia alba,* and *S. caseolaris* (Pattanaik et al. 2008). Another product collected from mangrove forests is honey, mostly reported in India (Badola and Hussain 2005; Pattanaik et al. 2008) and Indonesia (Rahman et al. 2018).

Communities also obtain proteins from shellfish such as oysters, snails, and crabs collected from mangrove areas (Rahman et al. 2018). In addition to being used as food for humans, the literature identifies the use of mangrove leaves as fodder/feed for animals. In Indonesia leaves of *Sonneratia*, *Avicennia* and *Rhizophora* are collected and fed to goats (Kusmana 2018; Rahman et al. 2018). In India cattle are left to feed in mangrove areas (Dahdouh-Guebas et al. 2006; Hussain and Badola 2010) and mangrove associates *Phragmites karka*, *Porteresia coarctata, and Myriostachya wightiana* are used as livestock fodder (Pattanaik et al. 2008). Following the use of mangroves as fodder for livestock in India, reduced pressure on pasture lands was recorded (Arunprasath and Gomathinayagam 2015). Historical use of mangroves for camel grazing is seen in Indus Delta in Pakistan (Meynell 1999). Mangrove is also food for crabs, a stable isotope analysis confirms that sesarmid crab (*Parasesarma bidens*) in mangrove forests in the Urauchi River in Japan utilize cellulose-rich mangrove detritus and leaf litter (Kawaida et al. 2019).

Commercial harvesting of mangrove wood for fuel has mostly been linked to the degradation of mangroves in Asia. Charcoal manufacturing was identified as a major cause of mangrove loss in Bintan, Indonesia (Winarno et al. 2016) and Myanmar (Estoque et al. 2018) causing a significant loss of mangrove cover hence calling for potential alternative sustainable solutions (Estoque et al. 2018). Another commercial harvesting is in brick kilns in India (Arunprasath and Gomathinayagam 2015). In the Philippines heavy cutting of mangroves for the commercial sale of firewood occurred between the 1930s and 1979 (Walters 2003) causing restrictions on cutting mangroves for fuelwood to be placed. Efforts of restoring areas degraded from charcoal production after failed natural regeneration are acknowledged in Matang, Malaysia (Eong 1993).

Mangrove utilisation in North America

About 15% (n=38) of the articles analysed were covering the North American region. The regulatory and supporting services of mangroves were more covered in this region than in South America. The contribution to fisheries was captured in 34% of the article, and both carbon storage and habitat utilization services were covered in 26% of the articles from this region (Figure 2.6). Like in Asia, all the 11 ecosystem services were covered

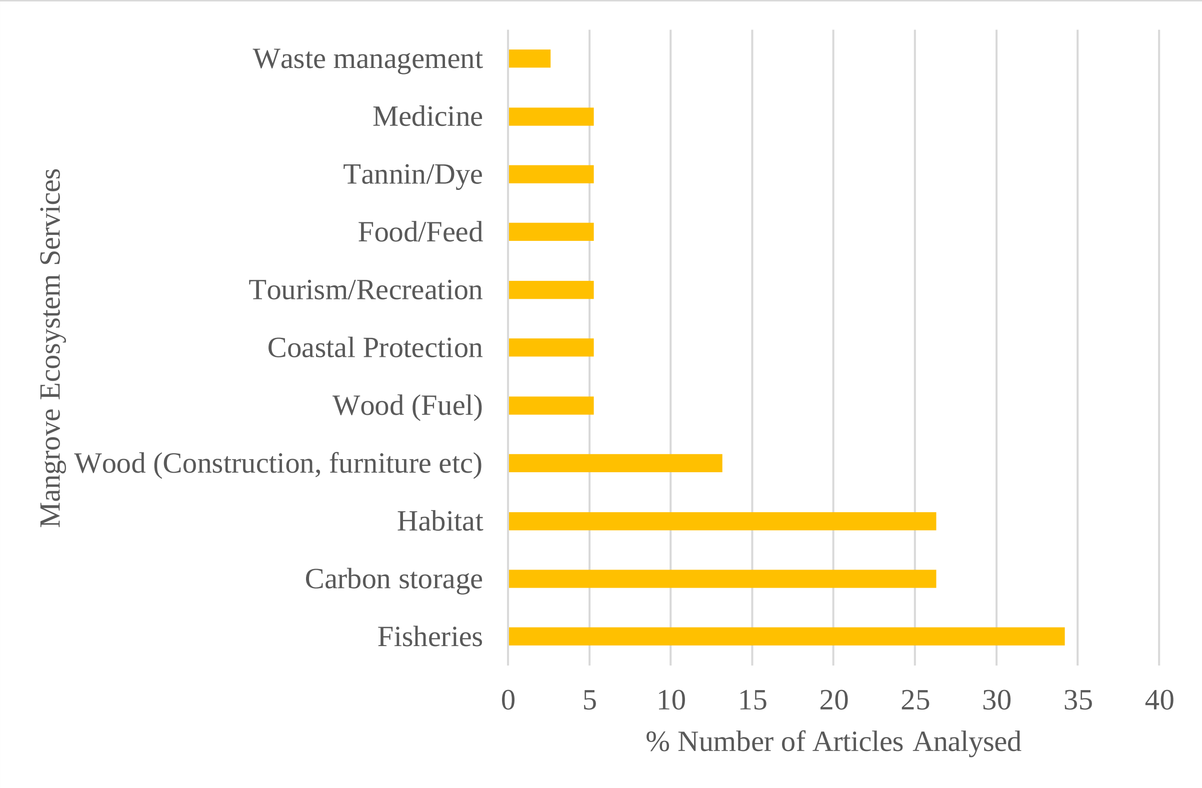

Figure 2.6: Distribution of articles analysed in North America

Historical use of mangrove wood in the 18th century is reported in Mankote Basin, in St. Lucia (Geoghegan and Smith 2002). In addition, archaeological findings on the ancient use of mangroves in construction are seen in peat bog in Colorado (Robinson and McKillop 2013). The use of mangroves in construction as well as domestic uses of mangrove fuel is observed in some areas in Mexico (Cornejo et al. 2005). Locals from Teacapan-Agua Brava in Mexico have been making beverages from mangroves and evidence of cattle feeding on *Avicennia* species is seen (Kovacs 1999). Locals in Mexico report using species such as *Rhizophora mangle* and *Avicennia germinas* as medicines (Kovacs 1999; Cornejo et al. 2005), and leaves of *Avicennia germinas* are used in the treatment of gastric diseases (Cornejo et al. 2005). The locals also produce soft drinks from mangroves some of which are medicinal e.g., tea derived from the bark of *Rhizophora mangle* is used to alleviate diabetes, kidney stones, and skin diseases and improve kidney function and purify the blood (Kovacs 1999). Past uses of mangrove products in Mexico include painting buildings and dyeing clothes with tannin produced from *Rhizophora* mangle (Kovacs 1999) and recent use of tannin in toughening fishing nets (Cornejo et al. 2005).

Mangrove utilisation in South America

Articles from South America were mostly on the contribution to fisheries, which was covered in 67% of the 30 articles from the region. The utilisation of mangrove ecosystem goods was well presented in this region compared to North America and Oceania. The use of mangrove wood (for construction and fuel) was covered by 13% of the articles. Except for carbon storage which was covered in 13% of the articles, the rest of the ecosystem goods and services were covered in less than 10% of the articles from South America (Figure 2.7)

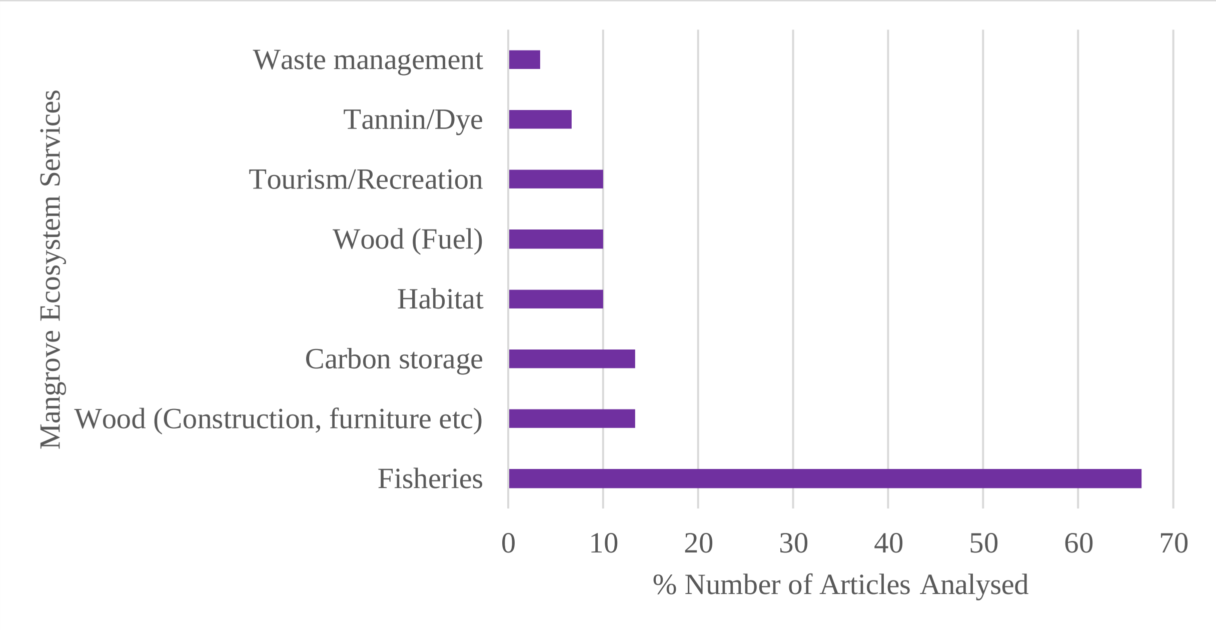

Figure 2.7: Distribution of analysed articles from South America

The historical use of mangrove roots for the construction of houses and boats was noted by the Warao people in Venezuela for over 7000 years (Bibi et al. 2019).

Domestic uses of mangrove fuel are reported in Brazil (Saint-Paul 2006). Commercial uses of mangrove fuel are observed in Colombia in charcoal production (Palacios and Cantera 2017) and brick kilns in Brazil (Saint-Paul 2006). Mangroves in South America like elsewhere around the world, are an important source of food, fodder for animals and medicines. Carney (2017) reports traditional uses of mangrove forests for medicinal purposes in Colombia, Brazil, and Peru. Although reported as an activity of the past, the use of mangrove tannin and dye is still practised in Brazil (Moreira dos Santos and Lana 2017). Tannin extraction from *Rhizophora* mangle was a common practice in the past but is still being undertaken to a low level. The activity of the past involves removing the bark from tree trunks and branches and boiling it for the extraction of dye used in fishing nets, wood floors and leather. Extensive deforestation was recorded in Brazil due to the increased production of leather tannin from mangrove bark *Rhizophora* mangle (Saint-Paul 2006). The literature reports a shift from using mangroves as the main source of income to use in subsistence and a decrease in domestic use of mangroves for fuelwood in Brazil (Moreira dos Santos and Lana 2017). A lagging economy and lack of alternatives for construction materials have made mangrove harvesting inevitable in Western Venezuela creating Tradeoffs between ecological preservation of mangroves and meeting human needs (López-Hoffman et al. 2006).

Mangrove utilisation in Oceania

Out of the 250 articles analysed, only 8% (n=20) were from Oceania. All these articles were on regulatory and supporting services of mangroves. The contribution of mangroves to fisheries was covered by 50% of the articles, followed by habitat function which was 45%. Carbon storage and the coastal protection functions are covered by 10% of the articles each (Figure 2.8).

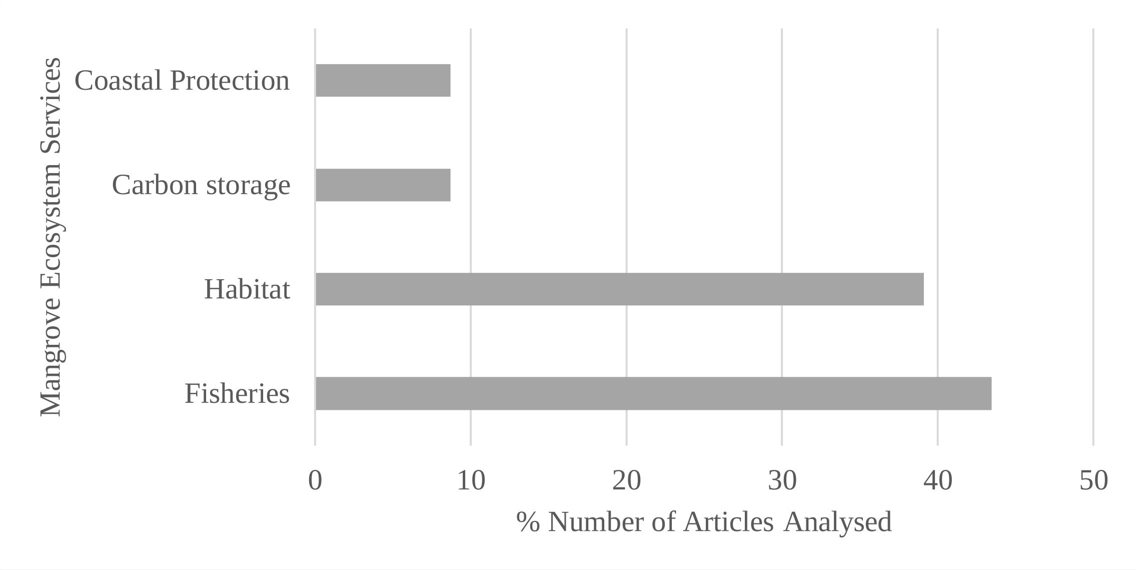

Figure 2.8: Distribution of articles analysed in Oceania

Mangrove utilisation in Africa

Africa was covered in 13% (n=33) of the articles analysed making it the third most covered continent after Asia and North America. The utilisation of mangrove wood for fuel and construction was covered in 39% and 30% of the articles from this continent. Contribution to fisheries and habitat was covered by 42% and 24% of the articles from Africa respectively (Figure 2.9). Except for waste management, all the other mangrove ecosystem goods and services identified in this study were covered in the articles from Africa.

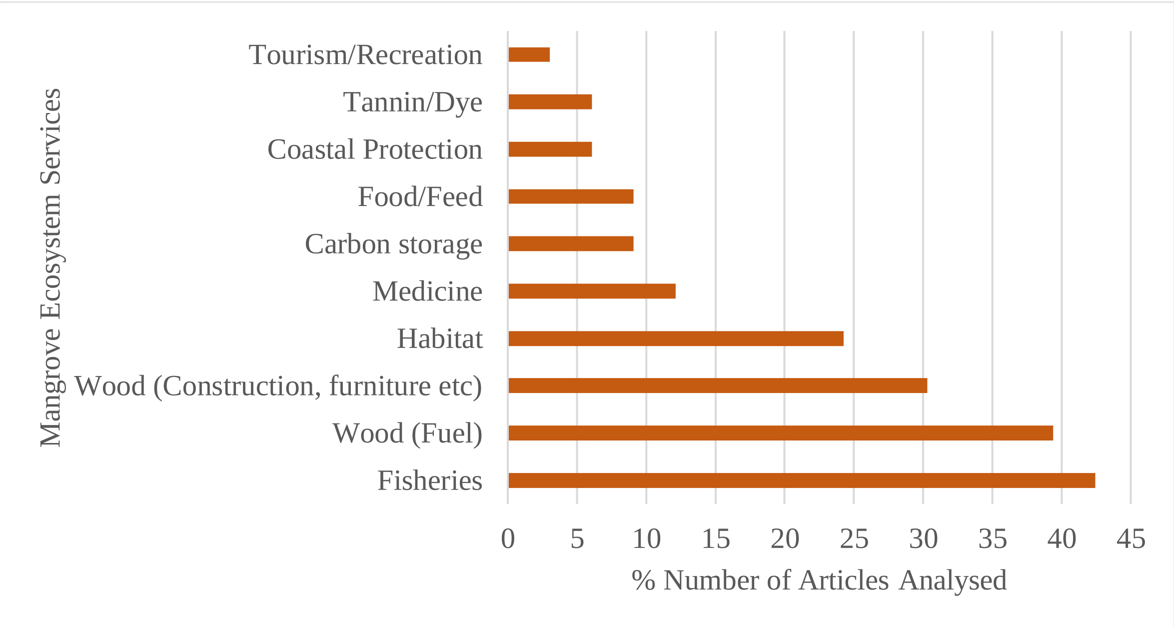

Figure 2.9: Distribution of articles analysed in Africa

The use of mangrove wood for the construction of houses is practised in several countries in Africa including Kenya (Abuodha and Kairo 2001; Rönnbäck et al. 2007), Senegal (Scales et al. 2018), and Madagascar (Conchedda et al. 2011). According to the literature analysed, domestic use of mangrove wood for fuel is common in Africa (Semesi 1998; Dahdouh-Guebas et al. 2000; Abuodha and Kairo 2001; Nfotabong-Atheull et al. 2009; Conchedda et al. 2011; Satyanarayana et al. 2012; Carney 2017). Commercial uses of mangroves as fuel are practised in Cameroon in smoking fish (Feka and Manzano 2008; Nfotabong-Atheull et al. 2009; Jiazet and Hans 2019), and in the production of lime in Madagascar (Scales et al. 2018; Scales and Friess 2019). Other uses of mangrove wood include the construction of fences observed in Madagascar (Scales and Friess 2019) and Cameroon (Nfotabong-Atheull et al. 2009). Like in Asia, mangrove wood is used in the fishing sector in the making of fishing gears e.g., fish traps, paddles, and boats (Rönnbäck et al. 2007).

Other products being harvested from mangrove forests in Africa include food and fodder for animals, medicine, tannin, and dye. In Kenya, mangrove dye is used to produce tie and dye fabrics and use to seal up tiny pores in trays woven from reeds and palm leaves (Dahdouh-Guebas et al. 2000). The traditional use of mangroves for medicinal purposes in East Africa is reported by Semesi (1998) and Dahdouh-Guebas et al. (2000). Medicinal products are made from the bark of the mangrove trees in Mida Creek, Kenya. Tree stems of different ages provide medicines for different ailments e.g., roots of *Rhizophora mucronata* provide curative properties for constipation, fertility, and menstrual disorders. *Xylocarpus granatum* is used to soothe aching muscles and limbs resulting from injuries. Evidence of traditional use of medicine from mangroves in West Africa is also reported (Carney 2017). Other products obtained from mangrove areas by communities include shellfish such as oysters, snails, and crabs (Carney 2017). Like in Asia and South America, making beverages from mangroves is reported in West Africa, in the Gambia tea is made from *Avicennia germinas* (Satyanarayana et al. 2012). The use of *Avicennia species* for animal fodder is also customary practice in East Africa (Semesi 1998).

The commercial harvesting of mangrove wood for fuel has mostly been linked to the degradation of mangroves. In Cameroon and most West-Central African coastal states, fuelwood extraction for commercial fish smoking was identified as a threat to the sustainability of mangrove ecosystems (Feka and Manzano 2008; Feka et al. 2009).

2.4 Discussion

The analysis of the 250 articles identified 11 key mangrove ecosystem services including fisheries, provision for habitat, carbon sequestration/storage, coastal protection, provision for wood, food and feed, medicine, tannin, and dye. The contribution to fisheries was the most covered in the literature followed by provision for habitat. The literature focused on ecosystem services which have a more pronounced economic value and may not always reflect all the uses or the importance of services to local communities. Of the articles, 42% were on fisheries and 23% on habitat and only 9% on the cultural values of mangroves. Furthermore, the cultural values of mangroves were only captured in literature from Asia and Africa. Also, recent developments and/or changes are guiding research e.g., carbon sequestration and coastal protection have been a topic of recent studies. This indicates the importance of the coastal protection service with changes in climate as coastal areas are threatened by rising sea levels and population increase (Huxham et al. 2015). In addition, coastal protection (a service focused on Chapter 4) has been identified as having the highest ecosystem value in the analysis. The literature indicates that mangroves are important carbon sinks at the local scale only (as most studies on carbon sequestration were local), even though many papers in the past have implied relevance at the global scale (e.g. Eong 1993). Mangroves can sequester a lot of carbon but overall, the global mangrove coverage is not large enough to make a significant impact on global emissions (Wylie et al. 2016).

The content of the 250 articles provides a reasonable account of utilization patterns of mangroves with most literature observed from Asia. This did not come as a surprise because Asia holds the largest coverage of mangroves (40%) with Indonesia alone having 19% of the world's mangrove cover (Spalding et al. 2010). Uses of mangrove wood have been observed as an ancient activity for the local communities living along the coast in the tropical and subtropical regions around the world. The quality of strength and suitability of the wood (Walters et al. 2008) and the resistance to salinity and termite attacks (Conchedda et al. 2011) make it more suitable and hence its use in construction globally. Globally, the extraction of mangrove wood for construction is limited to domestic consumption and local and regional markets (Walters et al. 2008). Together with medicine, the historical use of mangroves as a source of food for humans as well as fodder for animals was well presented in literature from Asia than in any other region. The medicinal potential of mangroves has been recognised in Africa and Asia but there is very little evidence of its use in other regions.

The review does not reflect changes in use for all services as few papers focused on changes in use over time. Nevertheless, the literature was able to capture changes in the provisioning service. A reduction in the use of mangrove wood for construction and fuel was noted in some Asian countries e.g., the Philippines and Indonesia. In the past mangrove wood was used for firewood and extraction of tannin. A decline in the production of tannin and dye from mangroves and the use of mangrove wood (construction and boat) is observed in Brazil. Harvesting of mangrove wood is reported as a past activity in Brazil and is currently valued more for fisheries contribution (Moreira dos Santos and Lana 2017). Demand for mangrove wood has grown from construction to fuel to use in marine products (seaweed and aquaculture) and the production of lime (Scales and Friess 2019). Prohibition of exploitation of mangrove wood after concerns for degradation in the Philippines in 1981were put in place (Janssen and Padilla 1999). Historical changes are noted in Mexico as well, dye obtained in mangroves in the past was used to paint houses but is currently used as a toughening agent for fishing nets (Kovacs 1999). In addition, salt extraction that was previously practised in mangroves has stopped (Kovacs 1999) and more so the traditional uses of mangroves have been seized e.g., its medicinal use on the Pacific coast.

Historically, with less development and with a close connection to nature in the past mangroves were valued more for their intrinsic values in many areas in Asia (Thiagarajah et al. 2015). The intrinsic value did not come out from the literature indicating a knowledge gap. For more effective conservation the intrinsic values of mangroves such as a sense of place, inspiration and cultural heritage need to be emphasized. The pattern of mangrove ecosystem service has a long history, in a review of literature by Friess (2016), between 1823 to 1883, studies were on provisional services for export. Regulatory services of mangroves such as erosion control and sediment accretion which are the current research focus have been recognized as early as 1865.

Like in many parts of the world, mangroves in Kenya are valued for both the harvestable resources and the ecological and environmental services. A review conducted on the utilization of mangroves in Kenya found that the direct uses of mangroves (wood for construction and fuel) were the most cited followed by the contribution to fisheries (Hamza et al. 2020). As observed in Asia and South America and some areas in West Africa e.g., Cameroon, commercial use of mangrove wood specifically as fuel (either in charcoal or lime production) has been a major cause of mangrove degradation. Also, in the literature in Asia conversion of mangrove areas to shrimp/aquaculture is one of the major causes of degradation in mangroves. On the contrary, in Kenya, the literature noted that commercial exports of mangrove is an activity of the past and at present mangroves are lost due to growing local demand with the root causes being population growth and economic pressure on development where mangrove areas are being cleared for infrastructure development (Hamza et al. 2020).

As in the rest of Africa, the cultural and intrinsic services are not well covered in the literature from Kenya. The need to document this value has been highlighted in Asia to ensure the effective conservation of mangroves. This is an area needing focus in Kenya and Africa at large. Also missing in the analysis is the water purification function and waste management as this ecosystem service has shown great economic value in Asia and South America.

2.5 Conclusions

The analysis of the 250 papers from the WoS provides a good overview of the mangrove ecosystem services and utilisation patterns of mangrove resources globally. Most of these articles are from Asia following the highest coverage of mangroves in that region compared to others. The contribution of mangroves to fisheries has received a lot of recognition by local communities and through research hence the most cited in the literature. The literature presents evidence of the carbon storage capacity of mangroves mostly at a local scale aimed at promoting mangrove conservation. Another mostly recognised mangrove ecosystem service is coastal protection and the reason for most mangrove restoration activity along with the coastal areas. The analysis further identifies coastal protection as an indirect service having the greatest value and has seen appreciation by local communities mostly those affected by extreme weather events. There is a noted similarity in the use of mangrove products across the continents with the use of wood for construction and fuel being the most cited. Historical changes in mangrove utilisation are presented with examples around the world but most importantly the study noted a reduction in the use of direct products observed due to the impacts brought by the extraction of resources. The utilisation of mangroves in Kenya is comparable to that presented in most areas in the world but differs in intensity. For example, the recreation and cultural services did not come out quite well in the literature. Lastly, the study was based on literature from only one database (WoS) (due to time limitations) although provided enough information to capture the aim and objectives of the study. Future research area would be to incorporate articles from other databases and see whether the analysis of changes in use could be fully achieved. Nevertheless, a study on a review of articles from Kenya which incorporated articles from WoS and Science Direct could not capture the historical changes in use from the literature obtained in these databases. Grey literature known to authors had to be incorporated to capture the history of use (Appendix II- publication on past and present uses of mangroves in eastern Africa and drivers of change).

3 Mangroves’ use and perceptions of local communities in Lamu County, Kenya

3.1 Introduction

Engaging local communities in decision-making has been identified as a key aspect of long-term sustainability and success of natural resource management (Kellert et al. 2000; Datta et al. 2012). Hence, it is becoming necessary to understand communities’ perceptions of changes happening in the environment. The use of questionnaires is common and effective to collect information from respondents to understand attitudes, habits, or behaviour regarding a particular subject (White et al. 2005). Questionnaires have been applied to understand community perception in aspects related to use and changes in mangroves in Malaysia (Sarmin et al. 2018), and Tanzania (Nyangoko et al. 2021). Sarmin et al. (2018) used questionnaires and demonstrated that changes in mangroves are perceived to have negative impacts on the livelihood of the people dependent on mangroves in Malaysia. Most recently a questionnaire-based study in Rufiji Delta (Tanzania) showed that people living further away from the mangrove forest were less likely to identify the ecosystem services they provide than people living nearby (Nyangoko et al. 2021).

Previous studies on this topic in Kenya have been conducted in Kwale (Rönnbäck et al. 2007) and Kilifi counties (Dahdouh-Guebas et al. 2000; Okello et al. 2019; Owuor et al. 2019). Dahdouh-Guebas et al. (2000) identified mangroves as the major source of wood for construction, fuelwood, and timber in Mida creek, Kilifi county. The survey noted the preference of mangrove tree species in construction activities. In Kwale County, on the other hand, Rönnbäck et al. (2007) found a strong dependence on mangrove resources, through the provision of 24 ecosystem goods, with food, traditional medicines, and wood for construction and fuel ranked as very important. This study also showed that natural mangroves are valued more than planted forests because of their ability to support other resources apart from mangrove poles e.g., vinegar, lime from molluscs, and insect control.

Most recently, Okello et al. (2019) and Owuor et al. (2019) assessed the perception of local communities on the status of mangroves in Mtwapa and Mida creek in Kilifi county, respectively. The community in Mtwapa creek noted a degradation of mangrove forests over the last 10 years with the harvesting of wood products perceived as the greatest threat (Okello et al. 2019). This study also identified climatic drivers contributing to the death of mangroves in Mtwapa creek.

Overharvesting of wood resources was reported to be a major threat to mangroves also by the Mida creek community, with pollution (plastic, faecal, and oil spill) and habitat encroachment identified as additional drivers of loss and degradation of mangrove forests (Owuor et al. 2019). Perceptions were influenced by demographic traits - in Mtwapa creek, women respondents either had no opinion on the status of the forest or perceived the forest to be very healthy, contrasting with most men reporting a state of degradation (Okello et al. 2019). On the other hand, older respondents (over 30 years of age) in Mida creek considered mangrove forests to be more degraded than the younger generation (Owuor et al. 2019).

All these studies point to the complexity of community use and management of local resources, with overlapping interests and differing perceptions which are affected by demographic characteristics of the local population, but by geographical location as well. Despite covering most of the mangrove area in Kenya (37,350 ha or 62% of mangroves in Kenya) and a long history of mangrove dependence (Idha 1998), little is known about the perceptions of local communities on the status of mangroves in Lamu. Furthermore, over the last five years, Lamu has witnessed infrastructure development which has impacted the local mangrove ecosystems and communities. Loss and degradation of mangroves reduce the resilience of the ecosystem making it more vulnerable to climate change effects like flooding and sedimentation (Lovelock and Ellison 2007). This chapter presents the results of household surveys in Lamu county to address the knowledge gap concerning the perceptions of local communities on the status and the uses of mangrove forests. Specifically, the study aimed to address the following questions:

1. What are the key mangrove ecosystem services for the communities of Lamu county?
2. What changes have the locals observed in the mangrove environment?
3. What are the perceived causes of these changes?
4. How does this perception vary across groups?
5. How are the local communities adapting to changes in the mangrove environment?

3.2 Methods

3.2.1 Study Area

Lamu County is a coastal county in northern Kenya (Figure 3.1). The county has a surface area of 6,475 km^2 that includes the mainland and over 57 Islands forming the Lamu archipelago. The largest habitable Islands are Lamu, Pate, Manda, Ndau and Kiwayu (Lamu 2017) (Figure 3.1). There are over 37,900 households in Lamu with an estimated population of over 143,900 people; and a density of 23 persons/km^2 (Kenya National Bureau of Statistics 2019a). The dominant ethnic group in Lamu is the Bajuni people whose main traditional livelihood is fishing, followed by mangrove harvesting, subsistence farming, and animal husbandry (Lamu 2017).

The principal mangrove species in Lamu are *Rhizophora mucronata* (MKOKO in the Swahili language) and *Ceriops tagal* (MKANDAA) which are exploited for wood and non-wood products (GoK 2017). Commercial harvesting of mangroves is a lifeline of communities in Lamu (Idha 1998; GoK 2017) and the wood is traded within and outside Lamu.

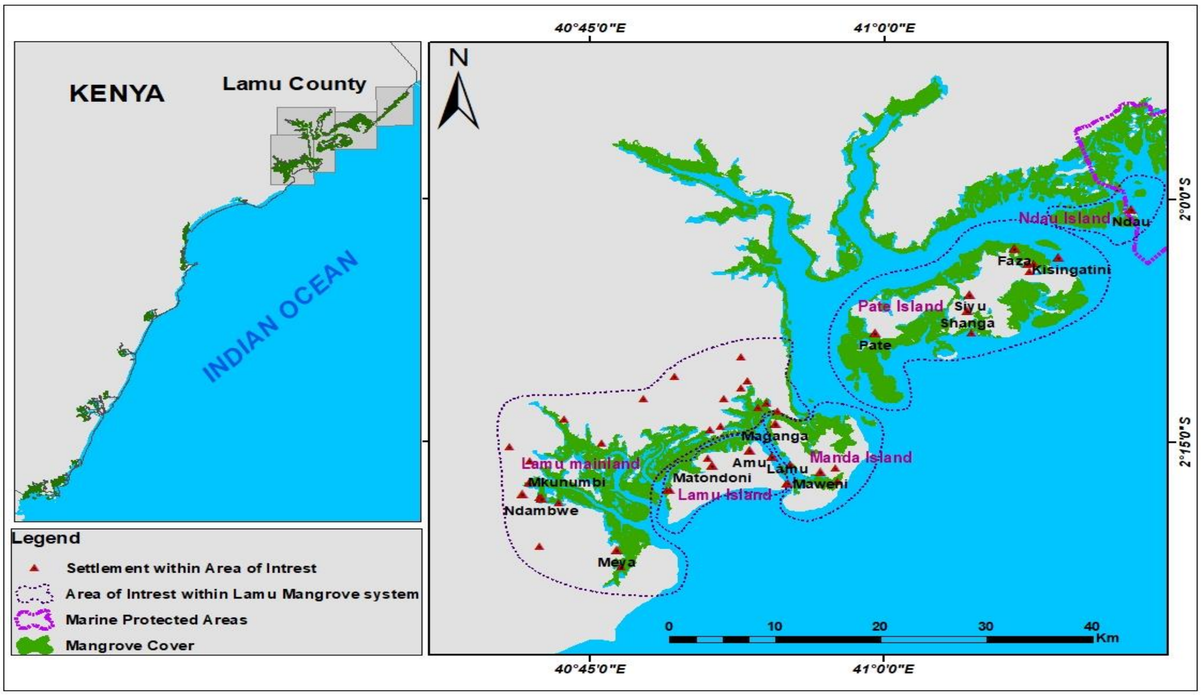

Figure 3.1: Map of Lamu county showing the study sites

3.2.2 Data Collection

To have a comprehensive understanding of local perceptions and to ensure that opinions of different users were captured, data collection consisted of focus groups with mangrove users and a household survey with household heads. The data collection followed the Economic and Social Research Council's framework for research ethics and ethical approval was granted (ID 27207) by Bournemouth University in compliance with its Code of Research Practice (2019-20) and Research Ethics Code of Practice (2019).

Focus groups

Nyumba *et al*. (2018) define a focus group (FG) as a technique where a group of individuals is assembled to discuss a topic to obtain beliefs, personal experiences, and perceptions through a moderated interaction. Four FGs of 10 participants were conducted with mangrove users in Lamu, Matondoni, Mkunumbi, and Pate villages (Table 3.1). These villages and the participants were selected with assistance from KFS to ensure the varying levels of mangrove dependence in Lamu county were represented. Pate Island portrayed the highest mangrove dependency while Lamu Island had the lowest. All the interviews were conducted in Swahili and lasted between 45 minutes to one hour. In addition to note-taking during the discussion, a voice recorder was used to ensure all viewpoints and inputs were registered.

The discussions were organized into three main themes:

1. Mapping resource use and dependence: Participants were asked to individually list the key ecosystem services (framed as "benefits provided by mangroves") on cards provided by the facilitator. The facilitator noted all the benefits raised and probed for more information to ensure that nothing was left out. The participants were then asked to rank the five most important benefits obtained. Furthermore, the participants were asked to annotate on a map the specific places where they obtain the mangrove resources.
2. Perceived changes in the environment: On the map presented, participants were asked to identify and mark the areas that have experienced changes over the last 10 years. The perceived causes of change indicated by participants were noted by the facilitator.
3. Adaptation measures: The participants were asked to individually list coping strategies for the changes happening in the environment. The identified strategies were discussed to ensure all relevant information was captured. Lastly, the facilitator asked for recommendations from other participants on how they could reduce the changes happening in the mangrove area.

Table 3.1: Date of focus groups in the four selected villages showing the number of male and female participants

Village	Date of discussion	No. of participants	
		Male	Female
Lamu	26th June 2019	7	3
Pate	3rd July 2019	5	5
Mkunumbi	12th July 2019	10	0
Matondoni	15th July 2019	3	7

Household survey

A questionnaire survey was administered to household heads to capture the uses of mangroves and dependency levels, as well as perceptions of changes in mangrove forests. The questionnaire comprised open and close-ended questions covering five main themes: socio-demographic characteristics, mangrove use and dependency, perceived changes in the environment, and adaptation to changes in the environment (Appendix III-Questionnaire used in the survey). A pilot survey was conducted using a sample of ten members of the community in Gazi village, Kwale county, in June 2019. The questionnaire was revised to ensure the questions were clearly understood by the respondents and suited to obtain the data required to achieve the intended objectives.

In July 2019, the revised questionnaire was then applied in the household survey conducted in five areas covering thirteen villages in Lamu county: Lamu Island (Lamu and Matondoni), Manda Island (Manda maweni and Manda maganga), Lamu mainland (Mkunumbi, Ndambwe, and Meya), Pate Island (Pate, Shanga, Siyu, Kizingitini, and Faza) and Ndau Island (Ndau) (Figure 3.1). According to the village heads, the number of households is 2,281 in Lamu Island, 2,018 in Pate Island, 580 in Lamu mainland, 370 in Manda Island, and 190 in Ndau Island. Starting from the south-eastern outcast of the settlement, every other house was sampled until at least 10% of the households per village were visited representing a total of 592 houses. To avoid repetition and interference from members of the same household, only one person per household was interviewed. The household head was the main respondent but where the head was not present, the eldest person present was interviewed. The interviewer asked the questions and systematically filled out the questionnaire. On average the interviews lasted 30 to 40 minutes and were conducted in Swahili.

3.2.3 Data Analysis

Answers to open-ended questions mainly on “adaptation changes to the environment” were coded into categories based on themes emerging from the responses. For example, responses such as selective harvesting / leaving certain areas for some time before going back to harvest were grouped under the topic of sustainable harvesting. Descriptive analysis was performed on numbers (n) and frequency (%) of responses. The Chi-square test of independence (χ^2) was used to determine whether there was any statistically significant association ($p < 0.05$) between responses, and demographics. The effect size was measured using Cramer’s V based on Cohen (1988) guidelines. Binary logistic regression was applied to predict the likelihood of using mangroves from a set of demographic variables. Statistical tests were performed using the Statistical Package for Social Sciences (SPSS V.25.0).

3.3 Results

3.3.1 Focus groups

The value of mangrove forests to the people of Lamu county varies across villages. When asked to rank the five most important benefits obtained from mangroves, the use of mangroves for construction was ranked first in Pate and Matondoni villages while mangrove support for livelihood (food, employment, clothing, education) was the most significant value in Lamu and Mkunumbi villages (Table 3.2).

Table 3.2: The five most important values of mangrove forests as identified by mangrove users in Lamu county

	Lamu	**Pate**	**Mkunumbi**	**Matondoni**
1.	Support livelihood	Construction poles	Support livelihood	Construction poles
2.	Construction poles	Boat construction	Construction poles	Fuelwood
3.	Fuelwood	Support livelihood	Support fisheries	Support fisheries
4.	Furniture	Fuelwood	Fuelwood	Support livelihood
5.	Water catchment	Furniture	Attract rainfall	Furniture

Focus group participants identified areas where harvesting of mangrove resources takes place in Lamu county as well as the hotspot for mangrove degradation. Harvesting of mangrove resources takes place in Kipungani, Pate, Wange, Indini Rewa, and Ndau. The degraded mangrove areas identified include Manda maganga in Manda Island, Mwambore in Kiunga, Chongoni in Pate Island, and Rewa in Kizingitini. Overharvesting of mangroves for lime production and use of power saw were some of the issues noted that are causing changes in the mangroves of Lamu county.

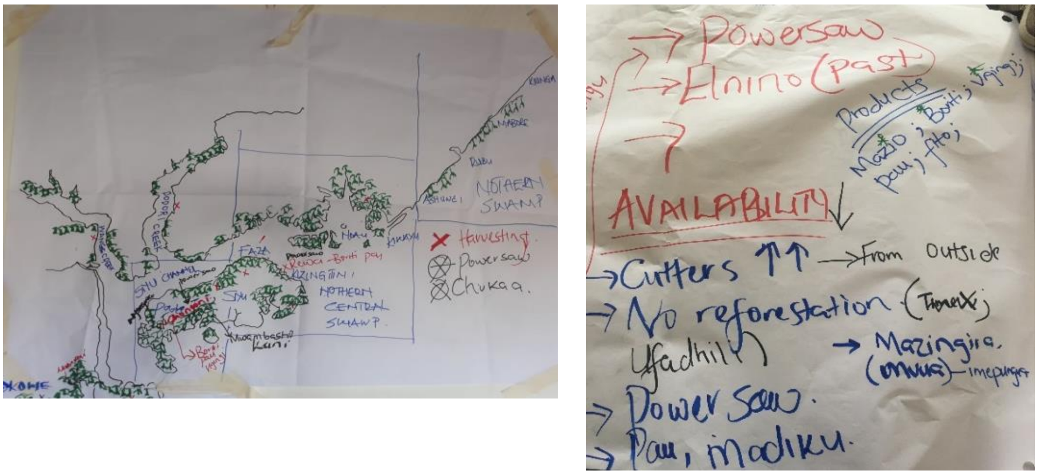

Figure 3.2: Causes of changes in mangrove areas as indicated by mangrove users during focus group discussions

Following the reduction in mangrove products in the last decade, locals have opted for wood products from terrestrial forests as an alternative to mangrove wood. Besides, the ban on mangrove harvesting, which was in place from 2018 to early 2019, forced locals to move to other strategies such as farming and fishing as alternative livelihood options to mangrove harvesting.

3.3.2 Household survey

The results of the household survey indicate findings on demographics of the respondents, current uses of mangroves, mangrove use and demographics of respondents, perceived mangrove ecosystem services, level of dependence on mangroves, perceived changes in the environment, and adaptation to changes in the environment.

Demographics of respondents

The survey targeted household heads. Most houses in the study area are culturally headed by men, who are the main decision-makers, and therefore respondents were dominantly men (66%). Most of the respondents were between the age of 35-59 (57%), and 37% of respondents did not attain any form of education (school or madrasa) (Table 3.3). The prevalence of respondents with no formal education was slightly higher than the national and county statistics as 20.1% of the population in Lamu county and 16.3% of the population in Kenya have not attained any formal education (Kenya National Bureau of Statistics 2019b). The household size of respondents ranged from 1 - 20 people with an equal mean and median of 6 (*SD=2.9*), which is above the average household size (3.7) for Lamu county (Kenya National Bureau of Statistics 2019a).

Fishing and small business were the most common primary occupation (18% each), followed by commercial mangroves harvesting (12%). There were noticeable variations across locations. While all respondents from Ndau Island were mangrove harvesters, they represented only 3% in Pate Island, where 25% of respondents were fishermen (Table 1). Most respondents from Ndau Island (65%) did not complete primary education, contrasting with only 13% from Manda Island (Table 3.3).

Table 3.3: Demographic traits of respondents

Demographics	N (Frequency)					Total
	Lamu Island	Pate Island	Lamu Mainland	Manda Island	Ndau Island	
Respondents	250 (42%)	242 (40%)	60 (10%)	23 (4%)	17 (3%)	592(100%)
Gender						
Male	168 (6 7%)	152 (63%)	36 (60%)	18 (78%)	16 (94%)	390 (66%)
Female	82 (33%)	90 (37%)	24 (40%)	5 (22%)	1 (6%)	202 (34%)
Age group						
18-34	60 (24%)	73 (30%)	14 (23%)	6 (26%)	3 (18%)	156 (26%)
35-59	146 (58%)	132 (55%)	30 (50%)	17(74%)	18 (82%)	339 (57%)
Over 60	44 (18%)	37 (15%)	16 (27%)	0 (0%)	0 (0%)	97 (16%)
Education level						
No education	53 (21%)	56 (23%)	9 (15%)	0 (0%)	0 (0%)	118 (20%)
Madrasa	45 (18%)	43 (18%)	13 (22%)	1 (4%)	1 (6%)	103 (17%)
Incomplete primary	51 (20%)	66 (27%)	16 (27%)	3 (13%)	11 (65%)	147 (25%)
Complete primary	53 (21%)	43 (18%)	18 (30%)	12 (52%)	4 (24%)	130 (22%)
Incomplete secondary	6 (2%)	8 (3%)	0 (0%)	3 (13%)	1 (6%)	18 (3%)
Complete secondary	25 (10%)	15 (6%)	2 (3%)	4 (17%)	0 (0%)	46 (8%)
Higher education	17 (7%)	8 (3%)	2 (3%)	0 (0%)	0 (0%)	27 (4%)
Others	0 (0%)	3 (1%)	0 (0%)	0 (0%)	0 (0%)	3 (1%)
Occupation						
Fishing	36 (16%)	57 (24%)	5 (8%)	0 (0%)	0 (0%)	98 (18%)
Small businesses (Owning a shop, selling foodstuffs)	48 (22%)	37 (15%)	8 (13%)	4 (17%)	0 (0%)	97 (18%)
Mangrove harvesting (poles and fuelwood) for sale	20 (9%)	7 (3%)	18 (30%)	1 (4%)	17 (100%)	63 (12%)
Casual worker	30 (14%)	22 (9%)	6 (10%)	2 (9%)	0 (0%)	60 (11%)
Farming	11 (5%)	19 (8%)	3 (5%)	4 (17%)	0 (0%)	37 (7%)
Crafting (hat, mat, etc.)	7 (3%)	14 (6%)	1 (2%)	0 (0%)	0 (0%)	22 (4%)
Employed (Having a monthly salary)	16 (7%)	3 (1%)	0 (0%)	0 (0%)	0 (0%)	19 (4%)
Makuti weaving	1 (0%)	9 (4%)	0 (0%)	0 (0%)	0 (0%)	10 (2%)
Construction/Mason	8 (4%)	0 (0%)	1 (2%)	1 (4%)	0 (0%)	10 (2%)
Mining	0 (0%)	0 (0%)	0 (0%)	8 (35%)	0 (0%)	8 (1%)
Lime making	0 (0%)	1 (0%)	0 (0%)	1 (4%)	0 (0%)	2 (0.4%)
Others (Tour guides, boat captains, plumbers, vendors, madrassa teachers)	42 (19%)	63 (27%)	6 (10%)	2 (9%)	0 (0%)	176 (30%)

The values in parentheses indicate percentages per total number of respondents for a demographic trait.

Current uses of mangroves

Results show that 89% of the 592 respondents use mangrove, of which 59% buy mangrove products, 28% harvest products for use, and 9% do both. Households in Lamu County are using mangroves for different purposes at the same time, with wood products being the most used in all areas, particularly for house construction (82%) and fuelwood (39%). Mangroves are also used for fishing activities (9%), sources of traditional medicine (3%), honey collection (2%), and making fishing gears (1%), but the proportion of users varies across the areas (Figure 3.3).

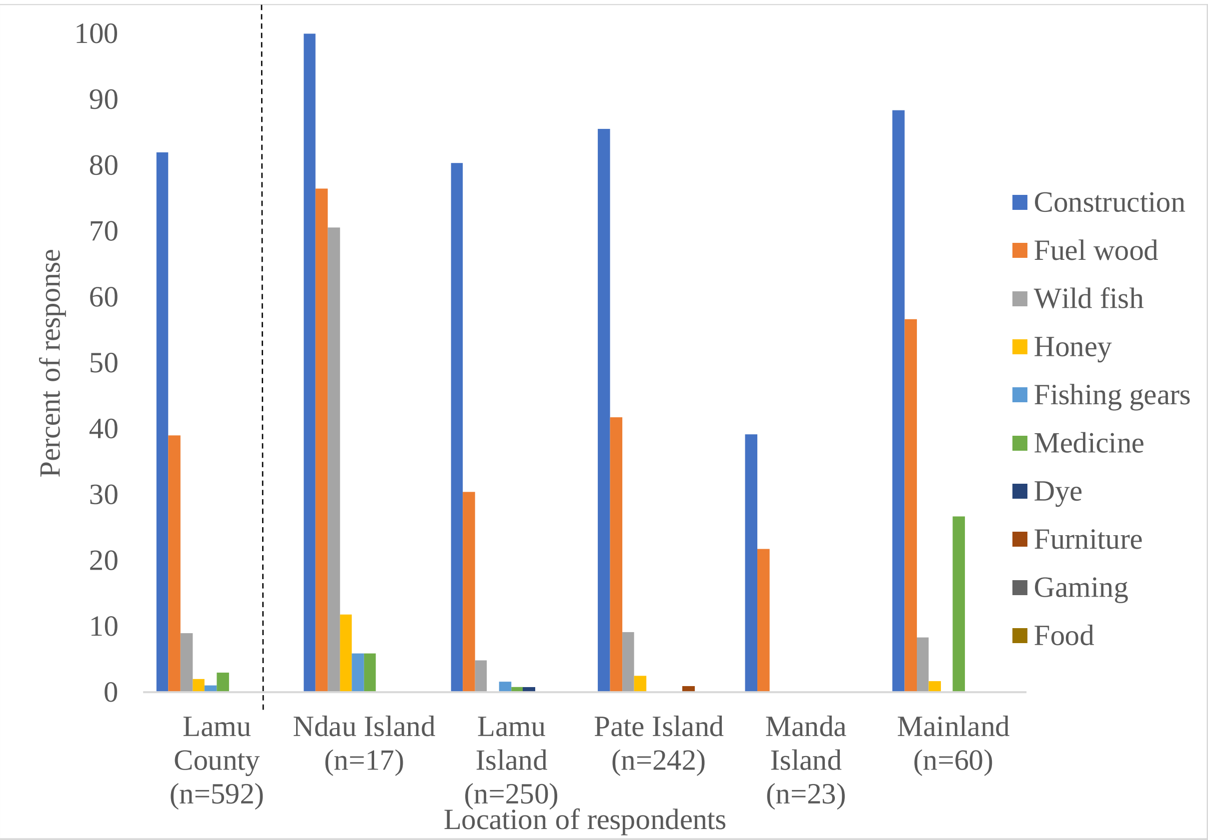

Figure 3.3: Response to the use of mangroves in Lamu county

Different mangrove species and tree parts are used for different purposes (Table 3.4). *Rhizophora mucronata* and *Ceriops tagal* were mostly preferred for construction (46% and 30% respectively) and fuelwood (44% and 38% respectively). *Avicennia marina* is used as a mosquito repellent by 27% of respondents in the Lamu mainland. Lime producers harvest all species and use the whole tree as fuel.

Table 3.4: Mangrove species preferred by respondents for different uses

Species	Uses (plant part)
Rhizophora mucronata	Construction (wood), firewood (twigs /whole tree in lime production), medicine (roots)
Ceriops tagal	Construction (wood), firewood (twigs /whole tree in lime production)
Avicennia marina	Fuelwood (Twigs / whole tree in lime production), mosquito repellents (twigs), gaming (seeds)
Sonneratia alba	Construction (wood), fishing gears (wood)
Bruguiera gymnorrhiza	Fuelwood (Twigs/ whole tree in lime production)

Mangrove use and location of respondents

All respondents from Ndau Island and Lamu Mainland use mangrove products while the lowest percentage of mangrove use in households has been recorded on Manda Island (57%) (Table 3.5). While all respondents in Ndau Island use mangroves for the construction of houses, only 39% report this use in Manda Island. The use of mangroves as medicine was mentioned by 27% of the respondents from mainland Lamu and by none from Manda and Pate Island. The use of mangroves in making furniture was noted only in Pate Island (1% of the respondents). Fishing in mangrove areas is prevalent in Ndau Island (71% of the respondents) and practised by less than 10% of respondents from other areas (Figure 3.3).

Table 3.5: The relationship between the use of mangroves and demographic traits of respondents (n=592)

Demographic characteristics	*n*	Mangrove use (% no response)		χ^2	*df*	*P*
		Yes	No			
Age				**12.043**	**2**	$<.001$
18-34	156	85.7	14.3			
35-59	403	72.6	27.4			
Over 60	33	89.9	10.1			
Primary occupation of respondents				**51.863**	**11**	$<.001$
Mangrove harvesting	63	100.0	0 .0			
Lime making	2	100.0	0 .0			
Fishing	98	91.8	8.2			
Farming	37	89.2	10.8			
Makuti Weaving	10	100.0	0.0			
Crafting (hat, mat, etc.)	22	95.5	4.5			
Small business	97	90.7	9.3			
Employed	19	84.2	15.8			
Mining	8	25.0	75.0			
Construction/ Mason	10	100	0.0			
Casual labourer	60	81.7	18.3			
Others	113	85.0	15.0			
Area				**35.653**	**4**	$<.001$
Lamu Island	250	86.8	13.2			
Manda Island	23	56.5	43.5			
Pate Island	242	90.5	9.5			
Mainland	60	100.0	0.0			
Ndau Island	17	100.0	0.0			
Gender of respondents				**0.021**	**1**	**0.886**
Male	390	88.7	11.3			
Female	202	89.1	10.9			
Education level of respondents				**9.199**	**7**	**0.239**
No education	118	89.8	10.2			
Madrassa	103	94.2	5.8			
Incomplete primary	147	88.4	11.6			
Complete primary	130	83.1	16.9			
Incomplete secondary	18	88.9	11.1			
Complete secondary	46	93.5	6.5			
Higher education	27	85.2	14.8			
Others	3	100	0.0			

There is a strong ($Cramer's\ V =$.375) and statistically significant association between the location of respondents and the use of mangroves for fuel ($\chi^2 = 32.188, df = 4, p < .01$) (Table 3.6). While 76% of respondents from Ndau Island use mangrove fuelwood for cooking, only 30% (n = 250) of respondents from Lamu

Island do the same, the rest either use charcoal (from the terrestrial forest) or cooking gas. Most of the respondents using gas for cooking confirmed to have used mangrove wood in the past but switched when cooking gas became affordable to them.

Table 3.6: Use of mangroves across the location of respondents

	n	**Location of respondents (%)**					χ^2	***df***	***p***	***V****
Resources obtained from Mangroves	(592)	Lamu (250)	Manda (23)	Pate (242)	Mainland (60)	Ndau (17)				
Construction	487(82)	201(80)	9(39)	207(86)	53(88)	17(100)	81.638	4	$< .001$	.409
Fuelwood	229(39)	76(30)	5(22)	101(42)	34(57)	13(76)	32.188	4	$< .001$	.375
Wild fish	51(9)	12(5)	0(0)	22(9)	5(8)	12(71)	24.376	3	$< .001$	.691
Medicine	19(3)	2(1)	0(0)	0(0)	16(27)	1(6)	2.078	2	0.354	.331

*V represents *Cramer's V*

Mangrove use and primary occupation of respondents

All respondents who harvest mangroves for sale or use them in construction (e.g., lime making, mason, and *makuti* weaving) are identified as users of mangrove products, while only 25% of those employed in the mining industry are mangrove users. Results from a logistic regression showed that there is a statistically significant ($\chi^2 = (11)\ 172.337, p < .01$) association between primary occupation and the likelihood of harvesting mangroves for own use. Unsurprisingly, respondents whose primary occupation is harvesting mangroves for sale are 113.5 times more likely to harvest mangroves for their use. The likelihood of harvesting mangroves for own use reduces considerably for other professions, with makuti weaving ranked second (Table 3.7). The model explained 37.9% (Nagelkerke R^2) of the variance in harvesting mangroves for use and correctly explained 77% of the cases.

Table 3.7: Regression coefficient on the likelihood of harvesting mangroves for different professions

	Wald	***df***	***p***	**Odds ratio**
Mangrove harvesting for sale	63.262	1	$< .001$	113.5
Makuti weaving	14.807	1	$< .001$	17.9
Fishing	27.510	1	$< .001$	6.5
Crafting	10.173	1	0.001	5.3
Casual laborers	7.320	1	0.007	3.0
Farming	4.894	1	0.027	2.9

Mangroves and perceived ecosystem services

Only 57% of respondents recognized mangrove forest services in addition to mangrove goods. The ecosystem services identified include fisheries support (bait, crabs, fish) (31%); climate regulation (absorbs CO_2 and other gases, brings rain, provides a nice breeze) (16%); coastal protection (15%) habitat for other organisms (animals, insects, fish) (8%); source of livelihood (a source of employment, education, clothing, health) (7%); and recreation and tourism (a place to relax, ecotourism, natural beauty) (2%). The provision of safety/rescue during boat accidents and shade was also mentioned.

There was a moderately strong ($Cramer's\ V = 0.248$) statistically significant association between respondents' recognition of mangrove services and household location ($\chi^2 = 72.670, df = 8, p < .01$). Most respondents from the Lamu Mainland (83%) and Manda Island (78%) could identify mangrove services, contrasting with only 29% of those from Ndau Island. Male respondents are more likely to recognize mangrove services than women. This association was found to be moderately strong ($Cramer's\ V = 0.182$) and statistically significant ($\chi^2 = 19.540, df = 2, p < .01$). A moderately strong ($Cramer's\ V = 0.172$) statistically significant association ($\chi^2 = 35.026, df = 14, p < 0.01$) was also found between education level and the ability to identify mangrove services. Most respondents who did not attain any education (53%) were unable to identify ecosystem services provided by mangroves.

Level of dependency on mangroves

There are clear differences between the locations surveyed on the level of dependency on mangroves (Table 3.8). Here, anyone with the main source of income relying on direct harvesting or extraction of products from mangroves or mangrove areas is considered mangrove dependent. A strong ($Cramer's\ V = .446$) statistically significant association ($\chi^2 = 428.522, df = 44, p < .01$) was found between the location of the respondent and the primary source of income (Table 3.8). All respondents from Ndau Island and 30% of respondents from Lamu mainland depend on mangroves, as their main source of income. The lowest percentage was recorded on Manda and Pate Islands (less than 5%).

Table 3.8: Occupation of respondents across locations

	n	Location of respondents					χ^2	df	p	V*
		Lamu	Manda	Pate	Mainland	Ndau				
Primary Occupation							428.522	44	$< .001$	.446
Mangrove harvest	63	20	1	7	18	17				
Lime making	2	0	1	1	0	0				
Fishing	98	36	0	57	5	0				
Farming	37	11	4	19	3	0				
Makuti weaving	10	1	0	9	0	0				
Crafting	22	7	0	14	1	0				
Small business	97	48	4	37	8	0				
Employed	19	16	0	3	0	0				
Mining	8	0	8	0	0	0				
Construction	10	8	1	0	1	0				
Casual labourer	60	30	2	22	6	0				
Others	113	42	2	63	6	0				

*V represents *Cramer's V*

Nine per cent of the 592 respondents obtain wild fish, shellfish and/or crabs from mangrove areas, particularly from the creeks, channels, and mangrove floors. There is a very strong ($Cramer's\ V =$.691) statistically significant association between the location of respondents and obtaining wild fish from mangroves ($\chi^2 = 24.376, df = 3, p < .01$) (Table 3.6). Seventy per cent of respondents in Ndau Island obtain wild fish from mangrove areas while none of the respondents in Manda Island obtain wild fish from mangroves.

Mangrove wood is considered a daily household requirement in some houses in coastal Kenya as it is used as fuel in cooking. Overall, 39% of the respondents in Lamu county use mangrove wood as fuel. There is a statistically significant association between obtaining fuelwood from mangroves and the location of respondents ($\chi^2 = 32.188, df = 4, p < .001$), and the association is strong $Cramer's\ V =$.375 (Table 3.6). Respondents in Ndau Island (76%), Mainland Lamu (57%), and Pate Island (42%) use fuelwood for cooking in their houses. Only 30% (n = 250) of respondents from Lamu Island use fuelwood from mangroves for cooking, the rest either use charcoal (from the terrestrial forest) or cooking gas. Similar to results from the focus group, most of the respondents using gas for cooking confirmed having switched from using mangrove wood when cooking gas became affordable to them.

Perceived changes in the environment

Changes in mangrove cover were perceived by 74% of the respondents, where 50% indicated an increase, and 24% a decrease in mangrove area (Figure 3.4). An increase in cover was reported by respondents from Lamu Island (58%), Manda Island (52%), and Pate Island (45%). Lamu Mainland had an almost equal response in an increase (42%) and a decrease in cover (40%) (Figure 3.5). A similar pattern of responses was found for changes in tree heights and density with the largest number of respondents indicating an increase. On the other hand, most respondents (81%) felt unable to assess changes in biodiversity and 71% indicated no changes in mangrove species (Figure 3.4).

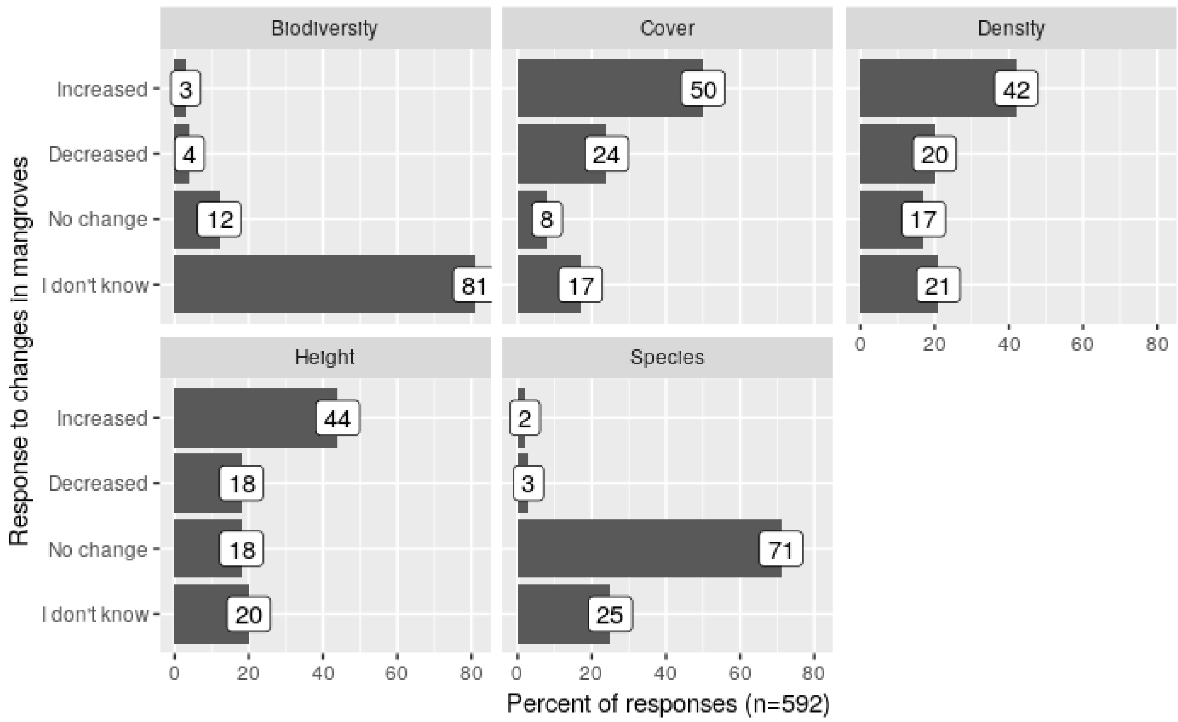

Figure 3.4: Response to changes in mangroves

Perceptions varied across locations with the largest percentage of 'no change' reported by respondents from Ndau Island in all aspects examined, species (94%), height (76%), biodiversity (71%), density (65%), and cover (59%) (Figure 3.5). A moderately strong significant association between location and responses regarding changes in mangroves cover ($\chi^2 = 60.372, df = 8, p < .01$); density ($\chi^2 =$

$32.961, df = 8, p < .01$); height ($\chi^2 = 41.545, df = 8, p < .01$); and mangrove species ($\chi^2 = 21.410, df = 8, p < .01$) ($Cramer's\ V =\ .248, .188, .209, and\ .155$ for cover, density, height, and mangrove species, respectively). A higher proportion of respondents from Lamu and Pate Islands, and Mainland reported an increase in cover, density, and height compared to other areas in Lamu county. There was no statistically significant association between location and response to changes in biodiversity.

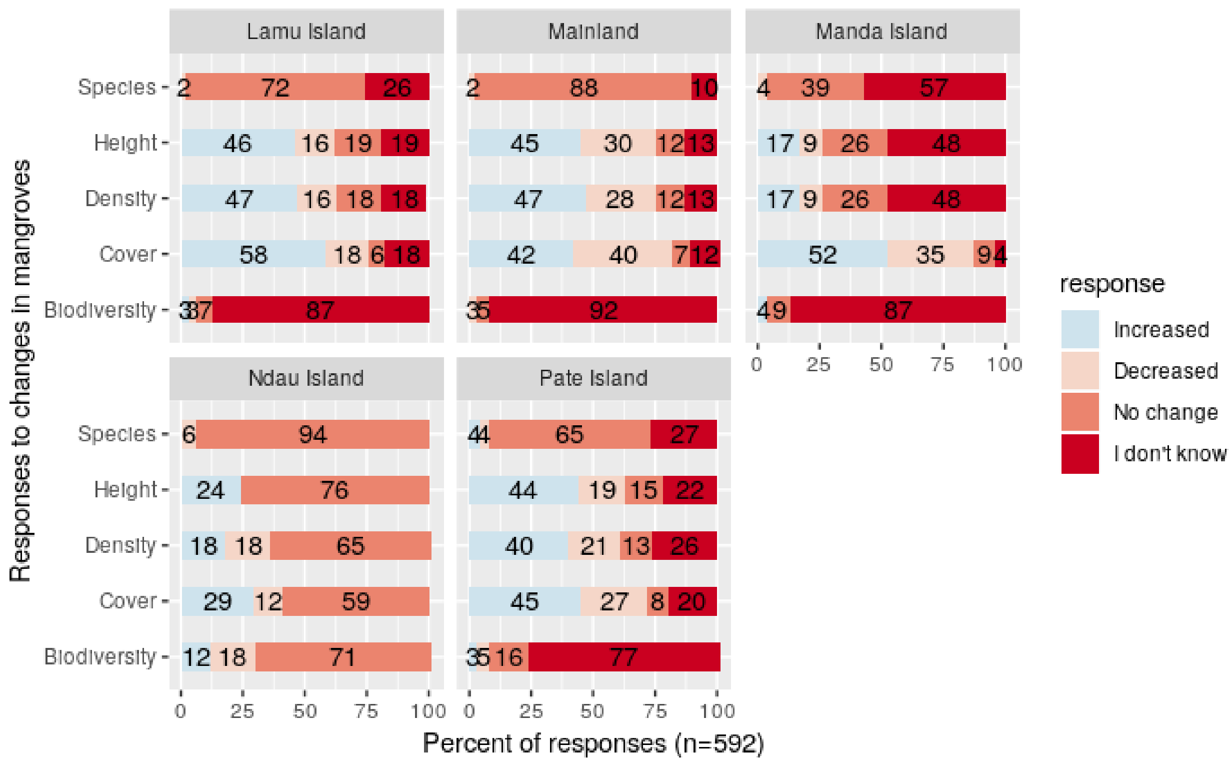

Figure 3.5: Response to changes in mangroves per location

There was a statistically significant association between gender and perception of changes in terms of mangrove cover ($\chi^2 = 53.570, df = 3, p < .01$); density ($\chi^2 = 33.112, df = 3, p < .01$); height ($\chi^2 = 40.530, df = 4, p < .01$); and species ($\chi^2 = 50.053, df = 3, p < .01$). These associations were strong for cover, density, height, and mangrove species ($Cramer's\ V =\ .301, .237, .262, and\ .291$, respectively). A larger percentage of women did not report changes happening in the mangrove forests compared to men (Figure 3.6). There was no statistically significant association between gender and response to changes in biodiversity.

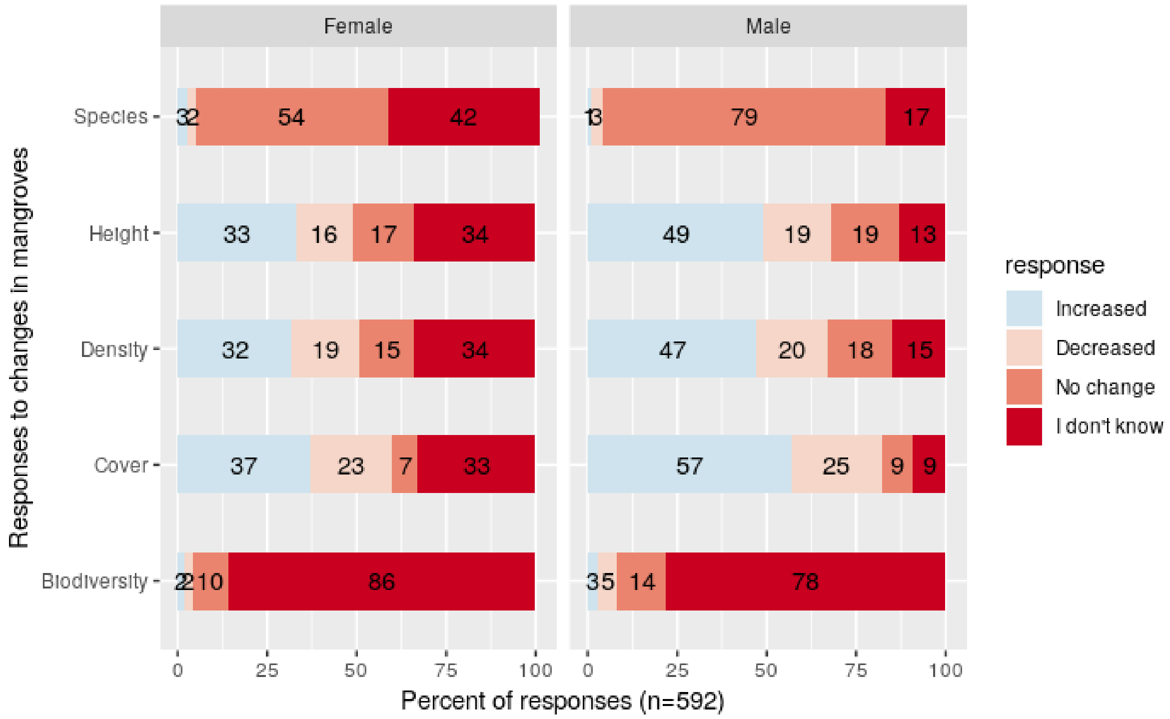

Figure 3.6: Responses to changes in mangroves by gender

Changes in the availability of mangrove products during their lifetime were noted by 77% of the 592 respondents. This was observed by a statistical significantly higher proportion (94%) of mangrove users (N=526) than non-users (6%) $(\chi^2 = 74.197, df = 2, p = < .01)$. The association was strong $(Cramer's\ V = 0.354)$. Mangrove users have noticed an increase in the availability of poles for construction (57%) and fuelwood (51%) and a decrease in the quantity of wild fish (52 %).

Wood harvesting was perceived as a major cause of change to the mangrove areas by 65% of 592 respondents, of which 59% indicated changes were positive and 41% denoted negative changes. A moderately strong $(Cramer's\ V = .254)$ significant association was found between respondent occupation and the kind of change they perceive is caused by logging $(\chi^2 = 22.956, df = 11, p = .02)$. A larger percentage of those who harvest mangroves for sale (78%) mentioned that logging brings positive change compared to other occupations like fishing (59%) and those who are employed (59%). Most of those working in crafting (75%) and mining (71%) and all *makuti* weavers believe that logging brings a negative change in mangrove areas.

Other causes of changes identified include enforcement of the mangrove ban (46%), siltation associated with heavy precipitations (13%), lack of awareness of the true value of mangroves (10%), the use of power saw (8%), reforestation (7%), agriculture (3%), fishing (2%), land reclamation (1%), residential and commercial development (1%) and erosion (1%). There was a strong $(Cramer's\ V = .359)$ statistically significant association between identifying enforcement of mangrove ban as a driver of change and the location of the respondent $(\chi^2 = 76.237, df = 4, p < .01)$. A larger proportion of respondents from Manda (74%) and Lamu Islands (63%) identified the ban on mangrove harvesting as a cause of change to the mangrove areas compared to respondents from Lamu mainland (48%), Pate (29%), and Ndau (24%) Islands.

Respondents had different views on the kind of change observed in the mangrove environments. For instance, a larger percentage of respondents from the mainland (86%) identified the ban on mangrove logging as a cause of positive change, compared to those in Lamu (59%) and Manda (59%), while respondents from Pate (52%) and Ndau (50%) indicated a negative change. This association was statistically significant $(\chi^2 = 12.443, df = 4, p < .05)$ and moderately strong $(Cramer's\ V = .213)$.

Respondents were asked about their level of agreement with selected factors causing changes in mangrove forests. Opinions were divided regarding climate change, droughts, human activity, and policy and conservation; views were more aligned on the effect of floods and poor management (Figure 3.7). Most respondents (68%) agreed that poor management is a cause of change to the mangrove forest while most (67%) strongly disagreed/disagreed that floods are contributing to changes. However, views vary across different communities. There was a statistically significant $(\chi^2 = 81.896, df = 16, p = < .01)$ and moderately strong $(Cramer's\ V = .195)$ association on the level of agreement to poor management across locations. Respondents from Lamu Island (51%) and Mainland (61%) strongly agree/agree and 59% of respondents from Ndau Island strongly disagree that poor management is a driver of change in mangrove areas. Also, a significant $(\chi^2 = 78.397, df = 16, p = < .01)$ and moderately strong $(Cramer's\ V = .191)$ association was also found between location and the level of agreement to the effect of floods. A much higher proportion of respondents from Ndau Island (88%) strongly disagree that floods are a cause of change to the mangroves compared to only 9% from Manda Island.

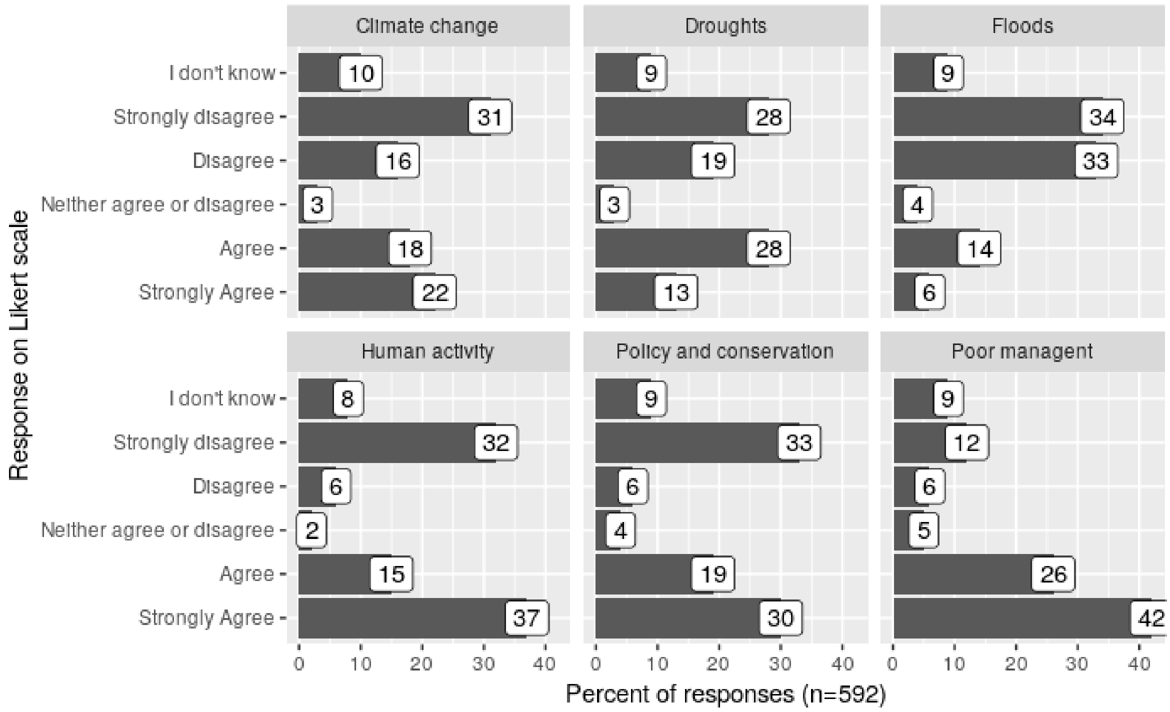

Figure 3.7: Response to Likert scale questions on causes of changes in the mangroves

Adaptation to changes in the environment

The adaptations most often mentioned by respondents included: planting mangroves (13%), changing the main source of income (6%), and using alternatives to mangrove wood products (4%). A significant association was found with education level, with respondents having a higher level of education more likely to use alternatives to mangrove products ($\chi^2 = 22.787, df = 7, p < .01$) and not having to change their main source of income ($\chi^2 = 21.906, df = 7, p < .01$), as they already have a stable source of income unrelated to mangrove harvesting. However, the associations were weak ($Cramer's\ V$ <0.2). No significant association was found between responses to adaptation options and the gender or age of respondents.

Most respondents from Ndau Island (76%), all of them mangrove harvesters, moved to alternative sources of income (e.g., farming) compared to Pate Island (6%), Mainland (6%), and Lamu (1%) Island. Planting mangroves in degraded areas was mentioned as an adaptation to changes by 20% of respondents from Pate, 10% from Lamu Islands and 8% from Mainland Lamu. None of the respondents from the Ndau and Manda Islands mentioned planting mangroves as an adaptation strategy. Statistically significant associations were found between the location of respondents and adapting by planting mangrove ($\chi^2 = 19.050, df = 4, p < .01$) and changing the main source of income ($\chi^2 = 168.121, df = 4, p < .01$). The association was moderately strong ($Cramer's\ V = .180$) for mangrove planting and very strong ($Cramer's\ V = .533$) for change in the main source of income. There was no statistically significant association between the location of respondents and the use of alternatives to mangrove products.

3.4 Discussion

3.4.1 Mangrove use and dependency level

According to Kenya Forest Service records, by 2019, 30,000 families were directly dependent on mangrove trade in Lamu county, which corresponds to 79% of the total households. If the dependency is determined by the main economic activity supporting the household, this research suggests a much lower proportion, as mangrove harvesting was reported to be the main source of income by 12% and a secondary activity for 13% of the 592 survey respondents (Table 3.3). This level of dependence seems smaller compared to e.g., local communities in Myanmar where in some areas on average 43% of an entire household income is generated through selling of forest products collected from the mangrove forest (Aye et al. 2019). However, the primary occupation alone does not reflect the total dependency of the local population on mangroves. Many workers are involved in the mangrove supply chain (Rawlins 1957; Idha 1998; Machava-António et al. 2020) as a secondary source of income, which often is essential to their livelihoods. Further, 89% of respondents in the household survey use mangroves routinely, e.g., for cooking, demonstrating the significance of mangroves as a resource for the local community.

As observed in similar studies in Kenya (Dahdouh-Guebas et al. 2000; Owuor et al. 2017) and elsewhere (Nyangoko et al. 2021), extraction of wood (construction and fuel), and fishing were the most common uses of mangroves reported in this survey. However, variations were observed across locations within Lamu county (Kairo 2001). The changing levels of dependency on mangroves across locations in this study its partially linked to the socio-economic structure of the local population, especially employment which was found to be statistically significant predictor of mangrove use. Overall, very low percentage of mangrove use was recorded for people employed in mining (25%), while in e.g., Makuti weaving and mangrove harvesting the percentage of mangrove use was 100%. Ndau is a traditionally mangrove harvesting area, as also reported by Kairo (2001), and higher levels of mangrove dependency are expected here. It is important that policy decisions and implementation engage the communities more dependent on mangroves. Local engagement should include the co-development of alternatives to minimise the impact on livelihoods, which is also likely to stimulate compliance (UNEP 2014). These dissimilarities in mangrove dependency also suggest variations in pressures on mangroves and differing perceptions of mangrove use and the ecosystem services they provide. Despite a high dependence on mangroves primarily as a raw material for construction and fuel, other ecosystem services were recognised by 57% of respondents. The most recognised ecosystem services by local communities (i.e., contribution to fisheries, climate regulation, coastal protection, and habitat provision) are also the most researched services as identified in the literature (Chapter 2). The importance of mangroves in fishing has been recognized by local communities in other parts of the world (Aye et al. 2019; Teka et al. 2019; Nyangoko et al. 2021) as well as climate regulation service of mangroves (Rönnbäck et al. 2007; Nyangoko et al. 2021).

The ability to recognise non-use ecosystem services is partly linked to levels of education recorded in this survey. People with higher levels of education (such as those from Lamu Island) were more likely to recognise ecosystem services they benefit indirectly, such as climate regulations, fisheries, and coastal protection. Respondents from Ndau showed lower levels of education and were less able/unable to identify non-use/indirect services, such as climate regulations and habitat provision. Nevertheless, respondents from Lamu Mainland were able to recognise the largest number of ecosystem services despite having 37% of people without formal education. While the level of education may not be the only factor contributing to the recognition of ecosystem services, including ecosystem services more explicitly and effectively in the content offered by local schools is likely to be beneficial. Not only the young generations will be more aware of the range of services offered by mangroves, which is likely to stimulate improved attitudes towards natural ecosystems in the longer term; they also transfer knowledge to older members of the family and community (Hungerford and Volk 1990; Tagulao et al. 2022).

3.4.2 Perceived changes in mangrove

The results from this survey show that the majority of respondents perceive there has been an increase in mangrove cover in the last 10 years. Remote sensing analysis shows a net decrease in mangrove cover in Kenya (Kirui et al. 2013) and Lamu county (Kairo et al. 2021), indicating that mangrove loss is overall higher than the increase in mangrove cover. However, hotspots of mangrove loss and expansion were identified in Lamu county (Kairo et al. 2021) suggesting that the specific location of respondents could have affected their perception of mangrove cover change. Kairo et al. (2021) report an increase in mangrove cover in the period 2010 to 2019 in the Southern Swamp (which includes the mangroves of the Mainland, Manda, and Lamu Islands) and a decrease in Pate Islands swamps and the Nothern Central Swamps (Pate and Ndau Islands). Similarly, a large percentage of respondents from Mainland, Lamu and Manda Islands reported an increase in mangrove cover in the last decade. On the contrary, together with Pate Island (where most participants perceived an increase in cover), Ndau Island, had the highest proportion of respondents claiming no change in mangrove cover (59%), and the lowest proportion of respondents reporting a decrease (only 12%). Respondents from Ndau Island (all being mangrove harvesters) also perceive the ban on mangrove harvesting to harm local communities, most people whose livelihoods depend on the forests. Similar resentment was reported from a ban in the past, for depriving the locals of one of their major sources of income (Idha 1998). This suggests that those depending on mangroves have a vested interest and might intentionally refrain from reporting negative impacts, as they fear further restrictions, respectively.

Socio-demographic characteristics such as economic status, education, and gender were noted to influence community opinions in resource management studies (Frank et al. 2017; Okello et al. 2019; Owuor et al. 2019). Education levels and gender are found to influence the response of the local communities in Lamu county regarding changes happening in mangroves. Men are more involved in mangrove harvesting, accessing wider areas and spending more time in the forest making decisions influenced by forest conditions. Fewer women usually visit mangrove forests; when they do, they only access nearby areas to undertake specific tasks, such as the collection of fuelwood and molluscs. Therefore, it is unsurprising that a significantly larger proportion of women than men felt unable to identify changes in the mangrove forests. In Rufiji (Tanzania), the ability of men to identify more mangrove services than females was attributed to their greater involvement with the forest (Nyangoko et al. 2021). Studies elsewhere in Kenya have also shown that mangrove forests under constant harvesting may not necessarily disappear, but are converted from a superior to an inferior forest stand of lower productivity (Kairo et al. 2002) It might be possible that perceptions of a decrease in mangroves refer to the quality rather than coverage area. Furthermore, the proportion of reported increase that was higher than expected in this survey could also be linked to the timing of the survey. The survey was conducted just after the government of Kenya had lifted the ban on mangrove logging in Lamu county which was in place for one year in the study area (Section 1.5). During the ban, forest recovery might have occurred which influenced the perception of the local community on changes in mangrove cover.

3.4.3 Perceived causes of change in mangroves

As much as wood harvesting was perceived as the most important cause of change in mangroves (65% of respondents), traditional methods of mangrove cutting were not considered a cause of forest degradation in this study, as in the findings of Kabii and Spencer (1996). Most respondents (59%), with a higher proportion of mangrove harvesters than other occupations, perceive that logging brings positive changes to the mangrove forest as it encourages forest regrowth. On the other hand, poor management linked to illegal harvesting using a power saw is highlighted as an important cause of negative changes in this study. The use of a power saw in harvesting mangroves is illegal in Kenya but was reported in Lamu mainland, Ndau, and Pate Islands. Illegal harvesting of mangroves has been reported as a major cause of change in other studies conducted in coastal Kenya as well (Dahdouh-Guebas et al. 2004; Mohamed et al. 2009; Bosire et al. 2014; Mungai et al. 2019). In Mida Creek (Dahdouh-Guebas et al. 2000).

3.4.4 Adaptation options for mangrove users

Whilst mangrove harvesting is an activity intrinsic to local identity (Idha 1998), results from this survey indicate the capacity for short-term adaptations to changes in local circumstances. Mangrove harvesters sought alternative sources of income (e.g., farming, fishing, and other income-earning activities) in response to the ban.

However, the switch was temporary, as they returned to harvesting as soon as the ban was lifted. According to Adger et al. (2005), improving safety and protecting economic well-being are some of the factors that can motivate adaptation. Burton and Paragahawewa (2011) state that policies that are not “culturally sustainable” will be abandoned if they fail to become embedded within the culture of local communities. Lack of skills to make a living from other trades was an issue of concern for respondents in the household survey. The community embraces changes if they have resources, as demonstrated by respondents from Lamu Island who have resorted to using gas instead of mangrove fuelwood to cook. The provision of alternative sources for cooking may reduce pressure on mangrove use if made affordable. Research in Eastern Europe demonstrated a shift back to fuelwood sourced from local forests when the gas price increased (Cvitanović et al. 2016).

3.5 Conclusions

This chapter presents results from a survey of 592 households from five locations in Lamu county aiming to understand local perceptions of the status and uses of mangroves. The respondents expressed high levels of dependency on mangroves, with the most common use being the source of wood for construction and fuel. Other benefits of mangroves identified include the contribution to fisheries and regulating climate. Overall, the local community reported a perceived increase in mangrove cover in the last decade, which is different from the main trends discussed in the relevant literature. This perception is partially linked to levels of dependency on mangroves, as those whose livelihood is dependent on mangroves report positive or no changes fearing restrictions on their main source of income. Other factors that might have influenced the perception of mangrove cover change are the location of the respondents as well as the timing of the survey. This research highlighted the potential for adaptation strategies, which include using alternatives to mangrove products (e.g., gas for cooking), planting activities, or changing one’s main source of income. However, these adaptation strategies were only temporary and were a necessity after the ban was introduced. The reason could be that these strategies were culturally unsustainable and failed to become embedded within the traditional culture of local communities which is historically linked to mangrove harvesting. Improving local skills and capacity to enable long-term changes in primary occupation and enhancing education, including ecosystem services obtained from mangroves can create long-term social changes that reduce pressure on mangroves. There is a need to understand the diversity within and between communities and to tailor the message concerning alternatives and management measures for mangrove conservation when engaging with different groups. Understanding this diversity and involving the community in decision-making is important to identify management and adaptation options that may apply to all communities and the ones that may suit specific locations.

4 Mangrove cover change and implications for the ecosystem services of coastal protection in Kenya

4.1 Introduction

Mapping mangrove cover over time gives us valuable information on the extent and the rate of mangrove cover change and the location of change (Alongi 2008). As mangroves provide a range of ecosystem services (Mukherjee et al. 2014; Friess 2016), mapping changes in mangrove cover can also help us understand the likely effect of these changes on the provision of ecosystem services (Donato et al. 2011; Lee et al. 2014) and plan for sustainable management (Lewis 2005).

Methods of mapping mangrove forests include *in situ* surveys, photo-interpretation of aerial photography and satellite imagery, which are becoming more accurate due to technological advancement (Ruiz-Luna et al. 2008). *In situ* and remote sensing methods complement one another (Bunting et al. 2018; Kairo et al. 2021). *In situ* monitoring can provide the most detailed information on the health and quality of the forest but is time-consuming and expensive as it is difficult to get around the mangrove forests, hence mostly used on a small scale (Younes Cárdenas et al. 2017; Maurya et al. 2021). Remote sensing (RS) through the analysis of aerial photography and satellite imagery has facilitated the monitoring of changes at the forest scale (Ruiz-Luna et al. 2008; Maurya et al. 2021). With appropriate support from *in situ* measurements, RS can be used to inform about species composition, the quality, and the health of forests, but mostly for specific areas and multiple management requests e.g., drought assessment, aquaculture activities and conservation (Kuenzer et al. 2011).

RS has been instrumental in monitoring states and changes in different ecosystems of spatial and temporal scales across the planet (Cohen and Goward 2004; Pettorelli et al. 2016; Yang et al. 2017). Due to the increased availability of global, freely available remotely sensed images, there has been a rapid development of datasets of mangrove extent and analysis of change since 1996 (Worthington et al. 2020). The Continuous Global Mangrove Forest Cover for the 21st Century (CGMFC-21) by Hamilton and Casey (2016) was the first consistent RS dataset on mangrove cover globally. Hamilton and Casey (2016) synthesized three global databases: the Global Forest Cover (Hansen et al. 2013), Terrestrial Ecosystems of the World (Olson et al. 2001), and Mangrove Forest of the World (Giri et al. 2011) to quantify changes in mangrove forest cover globally between 2000 and 2012. They estimate the mangrove cover in 2000 to be 83,495 km^2. Their results showed an average global loss of 137 km^2 of mangrove forest per year (or 0.16% per year) between 2000 and 2012, with Southeast Asia having the highest deforestation rate of 8.08% per year. More recently, Bunting et al. (2018) produced the Global Mangrove Watch (GMW) by compiling datasets of small-scale studies conducted at regional and local scales. The GMW assessed mangrove cover changes between 1996 and 2016 and provided a baseline of the global extent of mangroves for 2010 of 137,600 km^2. According to Bunting et al. (2018), the mangrove cover in 1996 was estimated at 141,939 km^2 which is 41% larger than that of Hamilton and Casey (2016) of the year 2000. Bunting et al. (2018) have also identified an overall loss in mangrove cover, estimated at 6,057 km^2 (0.3%) between 1996 and 2016.

While detecting changes in (tropical forest) land cover is straightforward using remote sensing coupled with field surveys (Thomas et al. 2017), identifying the drivers of these changes is a more challenging task. It includes the analysis of links between multiple land uses, and multiple responses to societal, climate and other environmental changes, as well as spatial and temporal dimensions of the causes and effects of these land changes (Geist et al. 2006). Underlying causes of mangrove change globally include economic development and population change which result in proximate drivers of change (Geist and Lambin 2002) like aquaculture and agriculture production in Southeast Asia (Richards and Friess 2016; Thomas et al. 2017), North and South America, West and Southeast Africa and Western India (Thomas et al. 2017) and extraction of wood for fuel in West Central Africa (Feka and Manzano 2008; Feka et al. 2009) and Asia (Winarno et al. 2016; Estoque et al. 2018). Changes in mangrove cover caused by anthropogenic drivers are augmented by natural processes such as erosion (Thomas et al. 2017). Following the increasing impacts of climate change, a rise in sea level will have a tremendous effect on low-lying ecosystems such as mangroves (Nicholls and Cazenave 2010).

In Kenya, the underlying driving forces of changes in mangroves have been identified as population growth, economic pressure, poverty, poor governance, and climate change (UNEP/Nairobi convention secretariat 2009), with the most commonly identified proximate drivers of change being conversion for agriculture, logging, and infrastructure extension (Abuodha and Kairo 2001; Bosire et al. 2016). These proximate drivers vary spatially, for example, research has shown that areas closer to human settlement are hotspots of mangrove cover change in Kenya (Bosire et al. 2014; Mungai et al. 2019; Kairo et al. 2021) and other parts of the world (Romañach et al. 2018).

Changes in mangroves can have a direct effect on the provision of ecosystem services (Donato et al. 2011; McIvor et al. 2015; Tran and Fischer 2017). The importance of coastal habitats in protecting the coast and in particular, the potential of mangroves to provide effective coastal defence is well elaborated (Arkema et al. 2013; McIvor et al. 2015). Ballesteros and Esteves (2021) focusing on coastal vulnerability in Eastern Africa, found that Kenya benefits most from its coastal ecosystems and hence is identified as the most vulnerable if it loses its mangrove forest. Other research has also identified coastal protection as one of the key ecosystem services of mangroves in Kenya (Owuor et al. 2019; Hamza et al. 2020). Therefore, it is important to understand how the modification of coastal habitats can expose coastal communities to storm-induced erosion and flooding. The main aim of this chapter is to understand how mangrove land cover is changing over time and the implication these changes have for the provision of ecosystem services, specifically coastal protection.

Objectives

1) Analyse changes in mangrove cover in Kenya and Lamu county based on existing global and local land cover data
2) Investigate the impact of changes in mangrove cover on coastal protection services using the InVEST coastal vulnerability model

4.2 Methods

This study compiled and analysed data from freely available mangrove datasets to quantify changes in mangrove cover in Kenya. The InVEST coastal vulnerability model was used to assess coastal exposure in Kenya and how it might be affected by the loss of coastal habitats.

4.2.1 Mangrove land cover change analysis

Mangrove cover data were obtained from various sources spanning from 1992 to 2016 (Table 4.1). For analysis of change at the country level global data from CGMFC-21, Global Mangrove Watch (GMW), Food Agricultural Organisation of the United Nations (FAO) and national data from the Government of Kenya (GoK) were used to calculate changes in mangroves. To extract mangrove land cover changes for Kenya from the global data sources, a shapefile from the United Nations Office for the Coordination of Humanitarian Affairs (OCHA, 2022) (https://data.humdata.org/dataset/cod-ab-ken), containing the political borders of Kenya was used. For the case study in Lamu county, data obtained from Kenya Marine and Fisheries Research Institute (KMFRI) was used.

To ensure consistency in time series analysis, only the maps which used the same satellite and spatial resolution, and the same image classification methods were then analysed using geographical information system (ArcGIS 10.6). Changes through time were quantified using the post-classification overlay detection method, which involved overlaying maps from two different years and identifying areas of gain, loss, and no change.

Table 4.1: Metadata on analysed data sets

Data source/Link	Method of RS data analysis	Accuracy	Resolution	Period of data	Notes on data	Reference
Global Mangrove Watch (GMW)	Random Forest Classification of a combination of L-band radar (ALOS PALSAR) and optical (Landsat-5, and Landsat-7) satellite data	95.3%	25m	1996, 2007-2010, 2015, 2016	Global extent of mangrove habitat (km^2) and length of coast with mangrove forests over 20 years.	Bunting et al. (2018)
Continuous Global Mangrove Forest Cover for the 21st Century CGMFC-21	Synthesis of 3 different databases to extract mangrove forest cover at high spatial and temporal resolution (Global Forest Change, Terrestrial ecosystems of the world and Mangrove Forest of the world)	Not reported	30m	2000 - 2012	Mangrove forest cover measures for 2000 to 2012 and estimates for 2013 and 2014 at global, National protected area scales.	Hamilton and Casey (2016)
Food Agricultural Organisation of the United Nations (FAO)	Landsat scenes interpreted using hybrid supervised and unsupervised digital image classification techniques	Not reported	30m	2000, 2008	Visual interpretation of high-resolution satellite images digitally enhanced through a homogenized and hierarchical classification system	Giri et al. (2011)
Kenya Marine and Fisheries Research Institute (KMFRI)	Vector map interpreted from aerial photographs collected from a survey in 1992 by the Kenya Wildlife Service and Forest Department	87.5%	30m	1992	Mangrove coverage in Kenya	Kirui et al. (2013) Bosire et al. (2014)

Data source/Link	Method of RS data analysis	Accuracy	Resolution	Period of data	Notes on data	Reference
Marine Database	within the framework of the Netherlands project					
Government of Kenya (GoK) National Mangrove Ecosystem Management Plan	Visual interpretation of Landsat images verified by extensive field visits	Not reported		2015	Mangrove coverage in Kenya including species identification	GoK (2017)
KMFRI Lamu Mangrove	Interpretation of Landsat images, SPOT and Sentinel images followed by intensive field campaigns	95%		2010, 2019		(Kairo et al. 2021)

4.2.2 Spatial analysis of mangrove cover change

The spatial analysis consisted of identifying changes in mangrove cover in the areas of interest in Lamu county – namely the Islands of Ndau, Pate and Lamu, as well as Lamu Mainland. This was followed by hotspot analysis where mangrove cover changes were assessed based on the distance from the main settlements.

To calculate the forest cover change in the area of interest, a post-classification overlay detection method in ArcGIS 10.6 was used. The KMFRI 2019 and 2010 shapefiles were overlaid and areas that had mangrove gain, loss, and no change were identified. For the hotspot analysis, the FAO land cover map 2008 was used as a reference point for settlement mapping. Google Earth was then used to systematically identify and manually georeferenced settlements that had more than 20 houses and covered an area greater than 1.5 ha and which were missing from the FAO 2008 map. Subsequently, multiple buffers were developed around the settlements (500m, 1 km and then 1 km increments to 9km) using the ArcGIS buffer analysis tool (Figure 4.1). The clip analysis tool was then used to calculate mangrove cover and loss in cover in the buffer regions to understand the relationship between the distance from settlement and changes in mangrove cover.

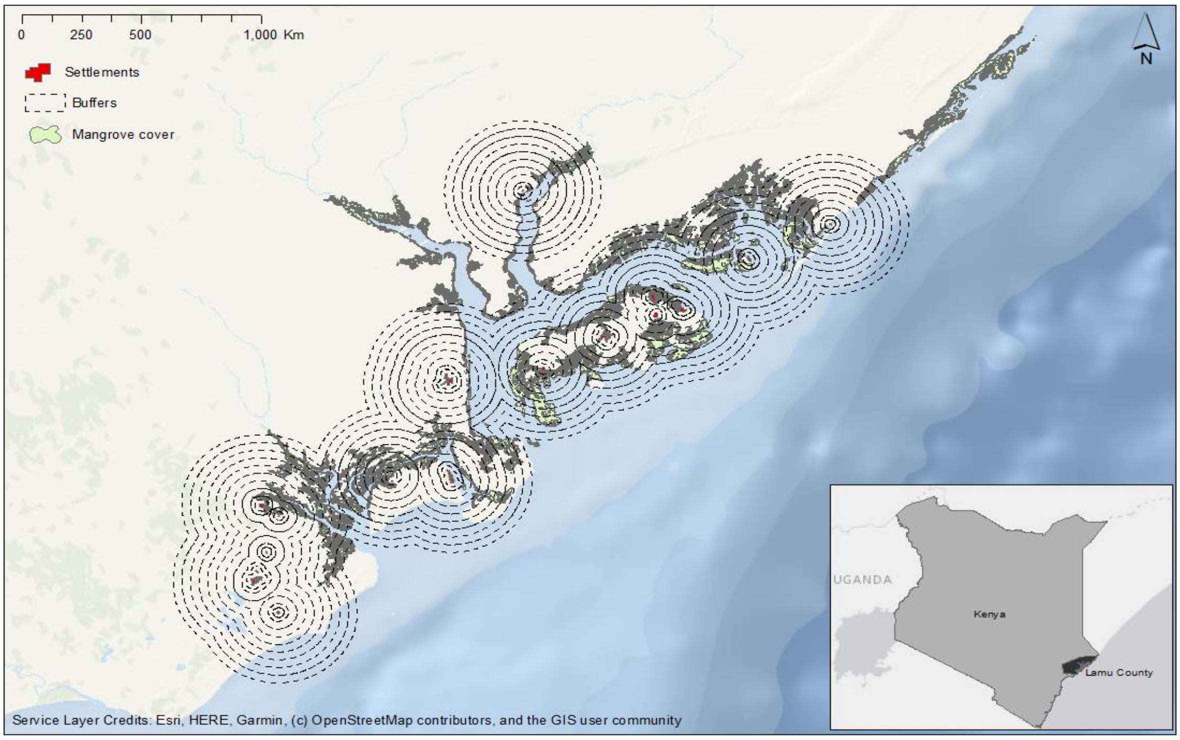

Figure 4.1: Buffers around settlements (500 m to 9 km)

4.2.3 Exposure to coastal hazards

To quantify the impact on the coastal protection service of the potential loss of mangroves, the model Integrated Valuation for Ecosystem Services and Tradeoffs (InVEST 3.9.2) coastal vulnerability of the Natural Capital Project (Sharp et al. 2020) was used. InVEST explores how changes in ecosystems can affect the flow of ecosystem benefits to the people. InVEST coastal vulnerability model uses both geophysical and natural habitat characteristics to calculate coastal exposure to erosion and flooding. The model uses quantitative data to create a relative ranking indicating which locations are more or less exposed within the study area (Sharp et al. 2020). It does not consider coastal processes that are unique to a region, nor does it predict long or short-term changes in shoreline position or configuration. The model has gained popularity and has been used to assess levels of exposure to coastal hazards at different scales around the world (Arkema et al. 2013; Hopper and Meixler 2016; Onat et al. 2018; Silver et al. 2019; Zhang et al. 2020; Ballesteros and Esteves 2021).

Data acquisition and preparation

The InVEST coastal vulnerability model requires the following user-defined settings and data inputs:

1. Area of Interest (AOI): a vector polygon of the area encompassing the landmasses within the AOI. A vector polygon of coastal Kenya and Lamu was created in ArcGIS which was then projected to coordinate system WGS84/UTM zone 37S.
2. Model resolution: the distance (in metres) between each point along the shore for the model to calculate the values of the indicators and the resulting IE. A resolution of 1000 m was considered appropriate for this study following previous studies (Arkema et al. 2013; Ballesteros and Esteves 2021).
3. Landmass: a polygon vector file representing the contour which the model uses to identify the shoreline (i.e., the boundary between the land and the sea). The model provides global landmass (Wessel and Smith 1996) as a default dataset but users are advised to incorporate data that better represent their area of interest. Hence, the landmass dataset for this study was obtained from the Database of global administrative boundaries (http://gadm.org), as it represented well the Kenya shoreline and country boundary. The Arc map 10.6 smoothing

Algorithm PAEK and smoothing tolerance of 130m were used to remove the serrated shape of the shoreline boundary.

4. WaveWatchIII: a vector file with grid points of the wind, and wave variables were extracted from WAVEWATCH III model which was embedded in the model. The data file presents the wind speed and direction used to compute the wind and wave exposure variables and ranking.
5. Maximum Fetch Distance: a user-defined distance (in meters) used to calculate the wave energy at the coast from ocean waves (swells) and/or locally generated waves. The model default value is 12,000 m (used here) and the maximum is 60,000m. The model calculates the fetch in 16 directions around each point along the coast, if the land is not intercepted within the defined maximum fetch distance, the coastal locations are considered to be exposed to ocean waves.
6. Bathymetry: a raster file obtained from General Bathymetry Chart of the Ocean 2019, https://www.gebco.net/data and products/gridded bathymetry data/gebco 2019 info.html. The data shows water depths in meters and as negative values required for wave height and period calculations.
7. Digital Elevation Model (DEM): a raster file was acquired from ASTER Global Digital Elevation Model (https://asterweb.jpl.nasa.gov) Showing the land elevation in meters (1 arc-second is approximately 30m)
8. Elevation averaging radius: a user-defined distance in meters used to compute the average elevation around each shoreline point.
9. Continental Shelf contour: a polyline that represents the edge of the continental shelf used to determine the surge potential
10. Natural habitat: The model determines whether a certain class of natural habitat is within a user-defined search radius from each point casted along the shoreline at 1 km intervals. Data of mangroves, coral reefs and seagrasses were available for the study area and were included in the analysis. The habitat shape files were obtained from the globally available dataset and recommended for such studies including Global Distribution of Coral Reefs (http://dta.unep-wcmc.org/datasets/1), Global Distribution of Seagrasses (https://data.unep-wcmc.org/datasets/7), and World Atlas of Mangroves (https://data.unep-wcmc.org/datasets/5). The model requires that the user defines the habitat ranking that defines the relative level of protection offered by each habitat (Table 4.2) and the assigned protection distance for each habitat, set as the values

suggested in the model documentation (2000 m for mangroves and coral reefs and 50 m for seagrasses), also adopted in earlier studies (Arkema et al. 2013; Ballesteros and Esteves 2021).

11. Geomorphology: used as a proxy for the susceptibility to erosion. Here, shoreline change rates estimated from satellite images for the period 1994 to 2018 in the global assessment by Luijendijk et al. (2018) were used (Table 4.2). Their data were provided at 500m spacing along the coast and rates were assigned to the nearest model points (1 km spacing), following Ballesteros and Esteves (2021). If the nearest shoreline change rate was more than 2 km from a model point, to be conservative, a ranking value of 5 was assigned.

Model run

The InVEST coastal vulnerability model was run using scenarios to assess the contribution of coastal habitats in reducing coastal exposure (e.g., Arkema et al. 2013; Cabral et al. 2019; Ballesteros and Esteves 2021). First, to assess the current level of exposure, all habitats (mangroves, corals, and seagrasses) were incorporated into the model run (with habitats scenario). Then the model was run excluding one of the habitats to assess the contribution of that particular habitat to coastal protection (scenarios with no mangroves, no corals, and no seagrasses). The model was run a fifth time excluding all habitats (scenario without habitats) to determine where and how habitats are contributing the most to reducing exposure to coastal hazards. The scenarios should not be interpreted as projections of future conditions. It is not implied here that all habitats or specific habitats will be completely lost. The exclusion of habitats is a way of assessing the overall and individual contribution of habitats to coastal protection by assessing how exposure would increase if they were lost.

Model output interpretation and analysis

The coastal vulnerability model calculates a relative ranking of coastal exposure to erosion and flooding from seven bio-geophysical variables (Table 4.2) in the form of a vulnerability index. The model ranks the value of each indicator to determine the level of exposure of a point along the coast in relation to other points in the area of study. The values of each indicator were ranked into 5 classes from 1 (very low exposure) to 5 (very high exposure) (Table 4.2). The exposure index was then calculated as the geometric mean of the ranks of each indicator (R*i*) each having equal weight. The resulting value was rounded to the nearest integer and assigned to the respective class (1- very low exposure to 5 very high exposure).

Coastal Exposure Index (IE) = $(R_{Relief} * R_{waves} * R_{wind} * R_{surge} * R_{habitats} * R_{erosion})^{1/6}$

Table 4.2: Ranking and classification of indicators used

Model input	**1 (Very low)**	**2 (low)**	**3 (Moderate)**	**4 (High)**	**5 (Very high)**
Relief	12.00 – 30.62	8.00 - 12.00	4.00 - 8.00	2.00 - 4.00	0 - 2.00
Wave exposure	0 – 0.1	0.1 – 2.00	2.00 -20.00	20.00 - 65.00	65.00 – 74.71
Wind exposure	0 to 20 Percentile	21 to 40 Percentile	41 to 60 Percentile	61 to 80 Percentile	81 to 100 Percentile
Surge potential	0 to 20 Percentile	21 to 40 Percentile	41 to 60 Percentile	61 to 80 Percentile	81 to 100 Percentile
Natural habitats	Coral reef; Mangroves	-	-	Seagrass	No habitat
Shoreline change rates (m/yr.)	> +2	+1 to +2	-1 to +1	-2 to -1	< -2

Model limitation

The dynamics of coastal processes occurring are simplified into the geometric mean of bio-geophysical variables to reflect exposure categories (Sharp et al. 2020). For instance, it does not consider how wind and waves change as they approach the nearshore, as observed by Sajjad et al. (2020). The model does not consider the quality of the habitats. The health of the habitat is a great determinant of its ability to provide ecosystem services including coastal protection (Barbier et al. 2011; Spalding et al. 2014). Hence the level of protection may be overestimated where habitats are degraded. Despite having these limitations, the model provides a space for assessing relative exposure to coastal hazards that can provide useful information on where to prioritize habitat conservation for coastal protection (Arkema et al. 2017; Silver et al. 2019).

4.3 Results

4.3.1 Changes in mangrove cover in Kenya

The reported mangrove cover in the analysed data sets ranges from 25,000 ha (CGMFC-21 in 2010) to 61,424 ha (GOK in 1992) (Figure 4.2). This observed difference does not necessarily reflect changes in mangrove cover over time but is probably due to differences in the methods of data collection and analysis.

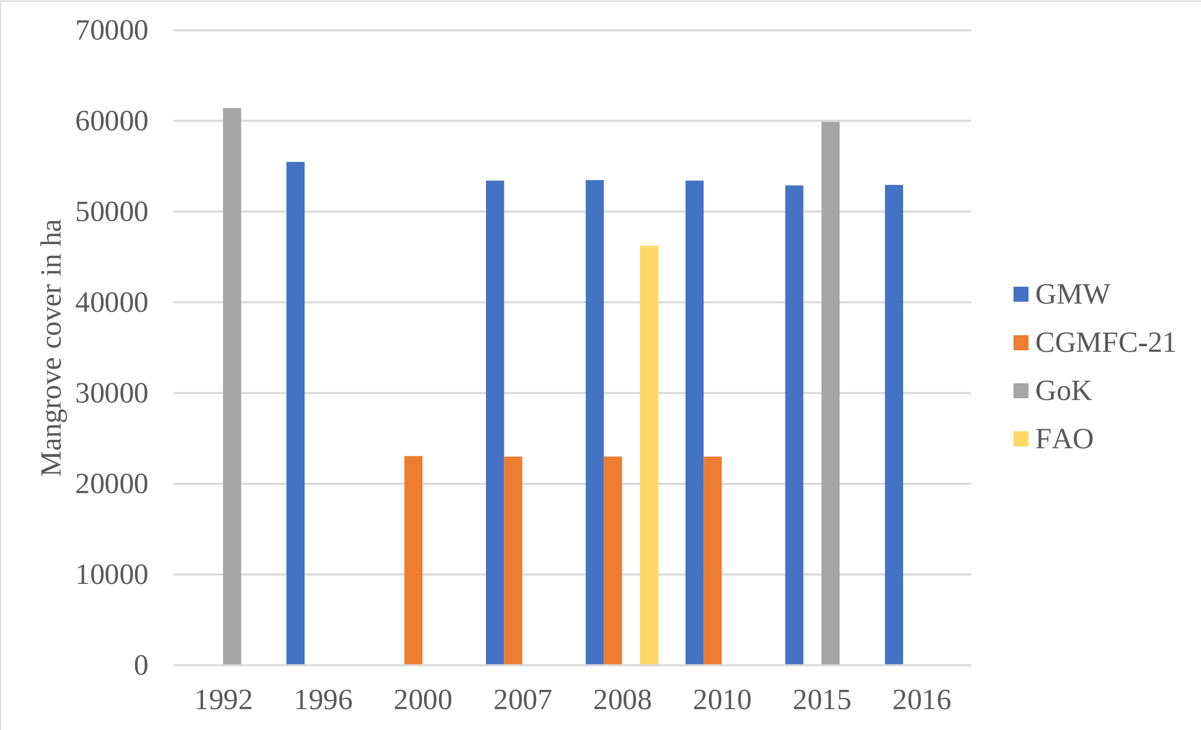

Figure 4.2: Kenyan mangrove cover (ha) from different data sources

Despite the discrepancies in the reported mangrove cover in Kenya, all the datasets indicate a small but consistent decrease in mangrove cover (Table 4.3)

Table 4.3: Changes in mangrove cover in the selected timespan

Data source	Change years	Total change (ha)	Gain (ha)	Loss (ha)	% Annual change
GMW (Kenya)	2010-2016	-485.3	1169.7	-1655	-0.15
GMW (Kenya)	2007-2016	-459.3	1191.4	-1650.7	-0.1
CGMFC-21(Kenya)	2000-2012	-35	-	-	-0.01
GoK	1992-2015	-1541			-0.11
KMFRI (Lamu)	2010-2019	-31.9	1262.3	-1294.2	-0.01

The annual mangrove loss also indicated discrepancies within the analysed datasets, with CGMFC-21 indicating a 0.01% annual loss and GMW and GoK showing a 0.1% annual loss (Figure 4.3).

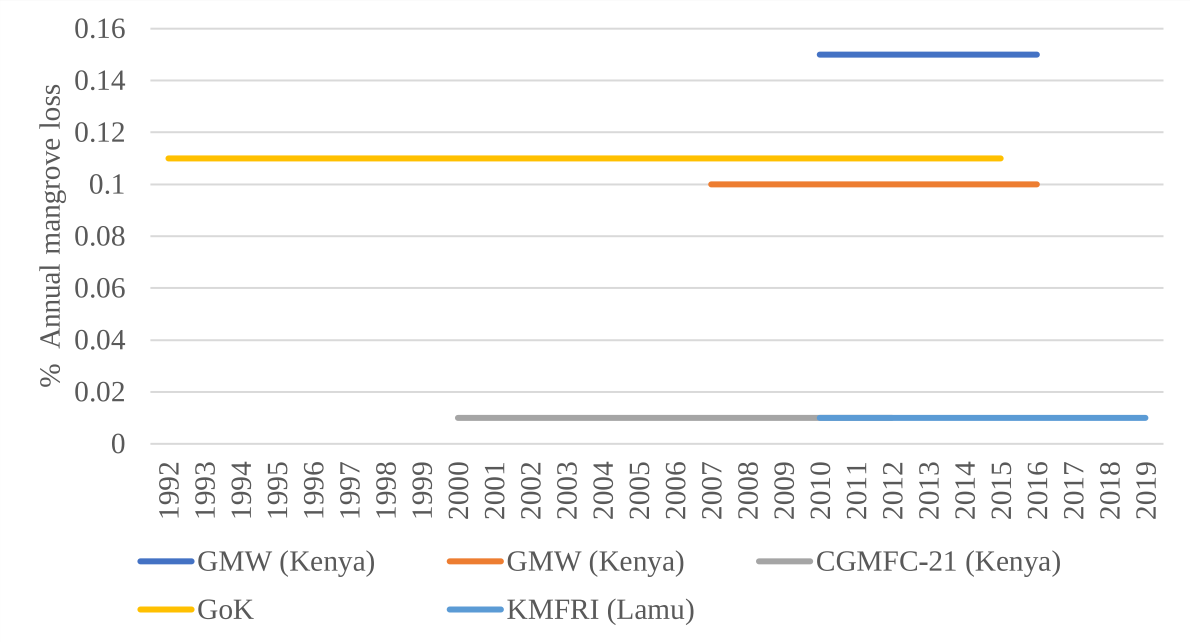

Figure 4.3: Annual loss of mangrove cover from different data sources for the timespan

4.3.2 Spatial analysis of change in Lamu county

Focussing on the areas of the household surveys in Lamu county (Chapter 3), Lamu Mainland and Manda Island have recorded a net positive change of 0.8 ha and 1.3 ha respectively within the period 2010 to 2019. The remaining Islands recorded a loss in mangrove cover with Pate experiencing the highest loss (20.2 ha), followed by Ndau (6.5 ha) and Lamu Island (1.2 ha) (Table 4.4). The annual rates of change were relatively smaller in all Islands with Ndau, Pate and Lamu Islands recording annual losses of 0.05%, 0.03% and 0.02% respectively.

Table 4.4: Changes in mangrove cover in Lamu county

Area	Gain	Loss	Net change	Annual change (%)
Lamu Island	37.45	-38.64	-1.19	-0.02
Lamu Mainland	307.75	-306.98	0.77	0.00
Manda Island	77.43	-76.1	1.33	0.01
Pate Island	201.64	-221.8	-20.16	-0.03
Ndau Island	16.88	-23.4	- 6.52	-0.05

The analysis of mangrove cover change for Lamu county within the period 2010 to 2019, indicate that most changes are happening closer to the settlements.

The largest changes (4.3% gain and loss) occur within 500 m from settlements. There is also a noted increase in gain and loss beyond 4km from the settlements (Figure 4.4).

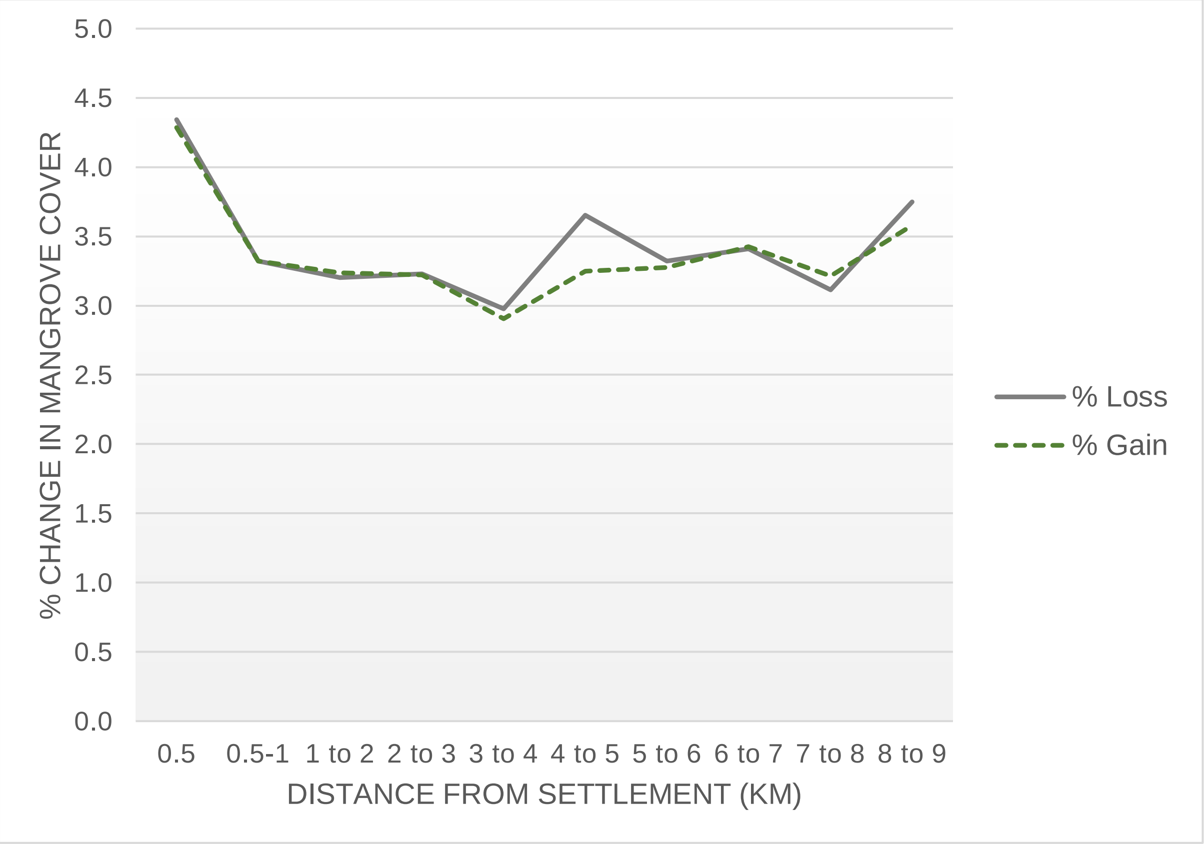

Figure 4.4: Mangrove cover change within the settlement

4.3.3 Coastal exposure in Kenya

Currently, 16% of the country's shoreline is at a higher (high and very high) level of exposure. Tana River is the most exposed county with 71% of its coastline at higher levels of exposure. All other counties have less than 50% of their shoreline at higher levels of exposure - Lamu (13%), Kilifi (18%), Kwale (10%) and Mombasa (0%) (Figure 4.5).

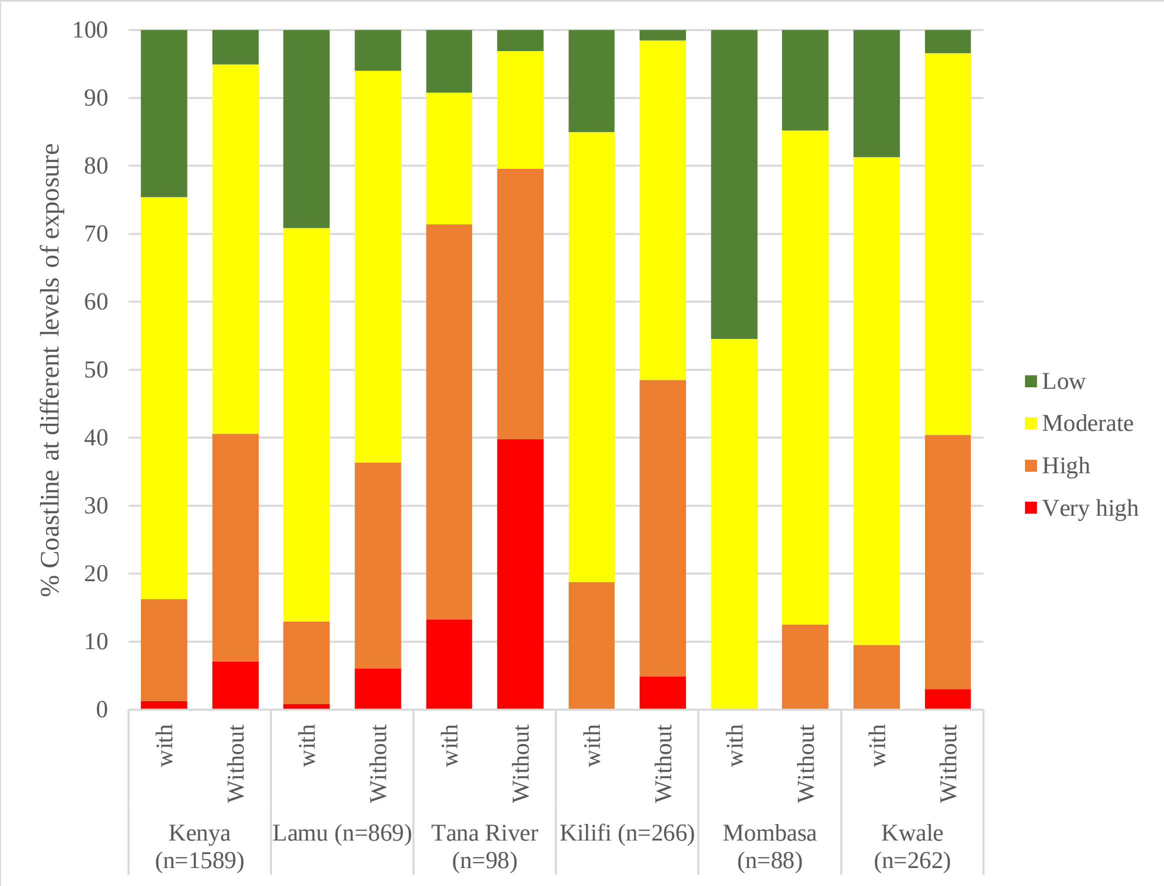

Figure 4.5: Proportion of country's coastline at various levels of exposure for the scenarios with and without habitats

The loss of habitats increases the proportion of the country's coastline at a higher level of exposure from 16% to 41%. Tana River would still be the most exposed county with higher levels of exposure increasing from 71% to 80% of its coastline. Other counties are benefiting more from the natural coastal protection offered by habitats, as evidenced by the larger increases in the proportion of coastline at higher exposure. Kwale and Kilifi benefit the most, with higher exposure increases from 10% to 41% and from 19% to 49%, respectively (Figure 4.5).

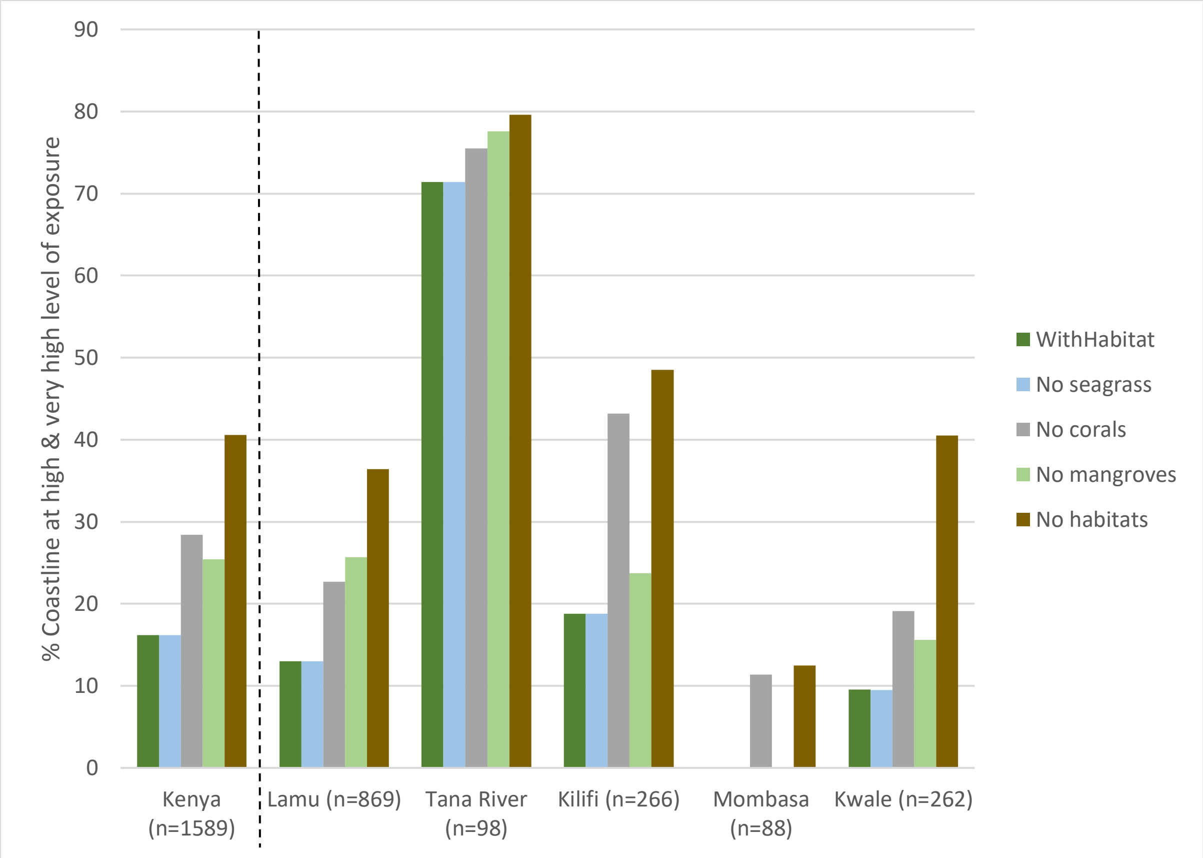

Figure 4.6: Different habitat contributions in reducing exposure levels along the Kenyan Coast

The analysis further shows that corals contribute the most to reducing the proportion of the Kenyan coastline that is at a higher level of exposure, then followed by mangroves (Figure 4.6). The contribution of the seagrass ecosystem to coastal protection is not seen as its absence seems not to be impacting the proportion of coastline under higher levels of exposure. At the county level, mangroves contribute the most in reducing the proportion of shoreline at higher exposure levels for Lamu and Tana River county while coral reefs play a bigger role in Kilifi, Kwale and Mombasa.

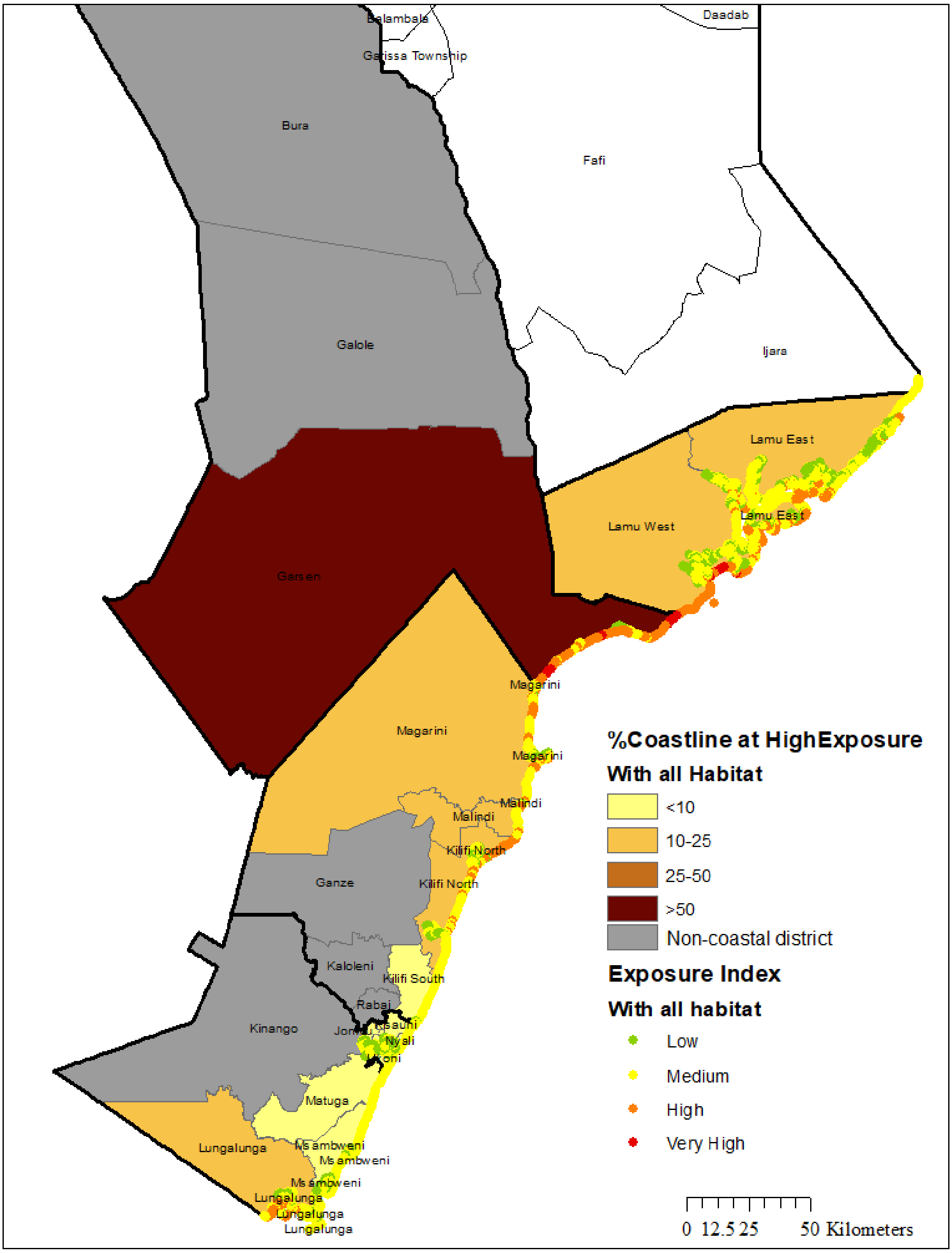

Figure 4.7: The proportion of the county's coastline at high exposure levels is indicated by the shading and exposure level of the data points along the shoreline for the scenario that includes all habitats.

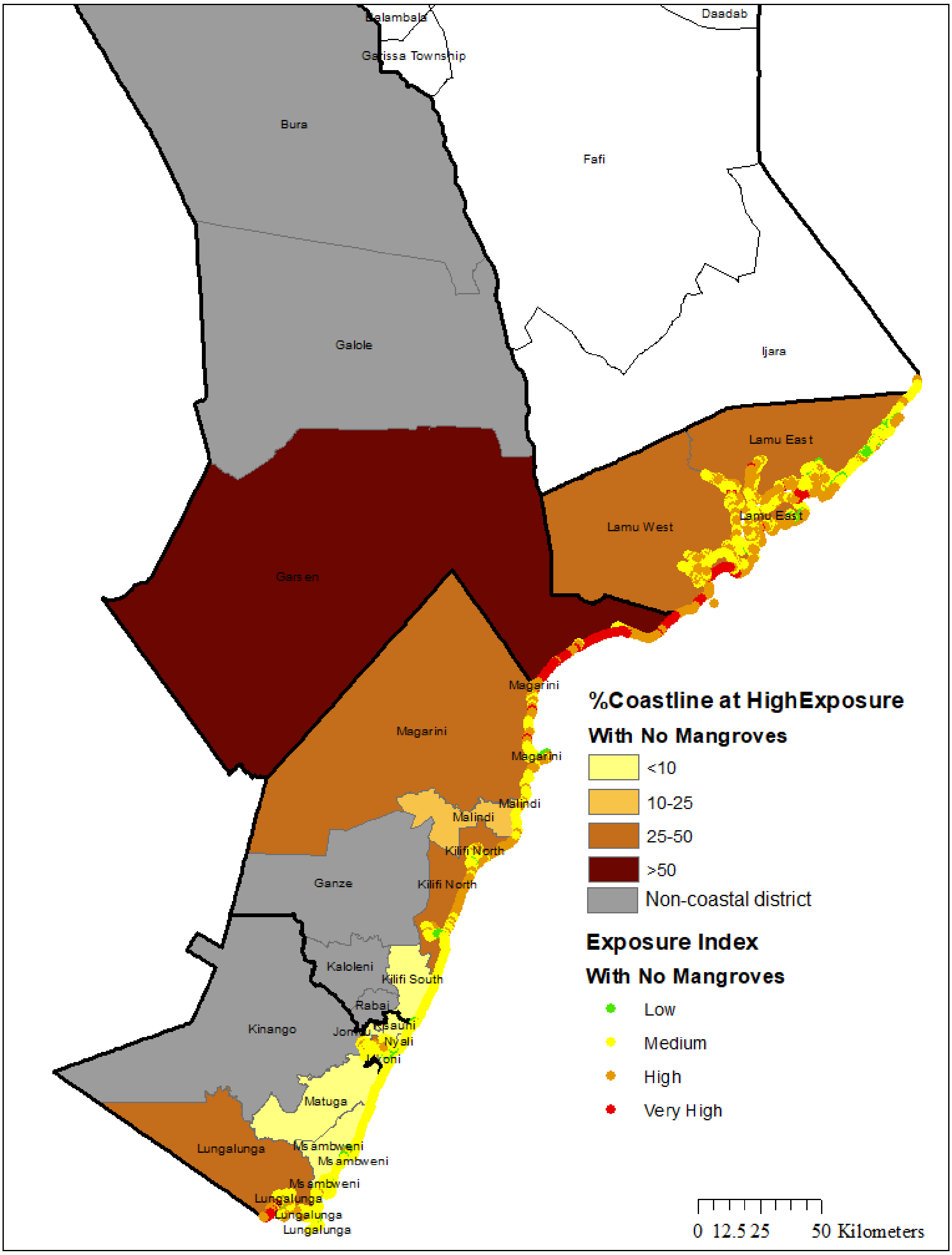

Figure 4.8: The proportion of county's coastline at high exposure levels indicated by the shading and exposure level of data points along the shoreline for the scenario that is with no mangroves

Kenya has an average IE of 2.4, with Tana River county having the highest average IE of 3.2 followed by Kilifi county (2.5). Lamu and Kwale counties have an average IE of 2.4 equivalent to the country's average. The wind is the indicator contributing the most in the counties where the average IE is above the country's average. The rest of the counties have erosion as the most contributing indicator (Figure 4.9).

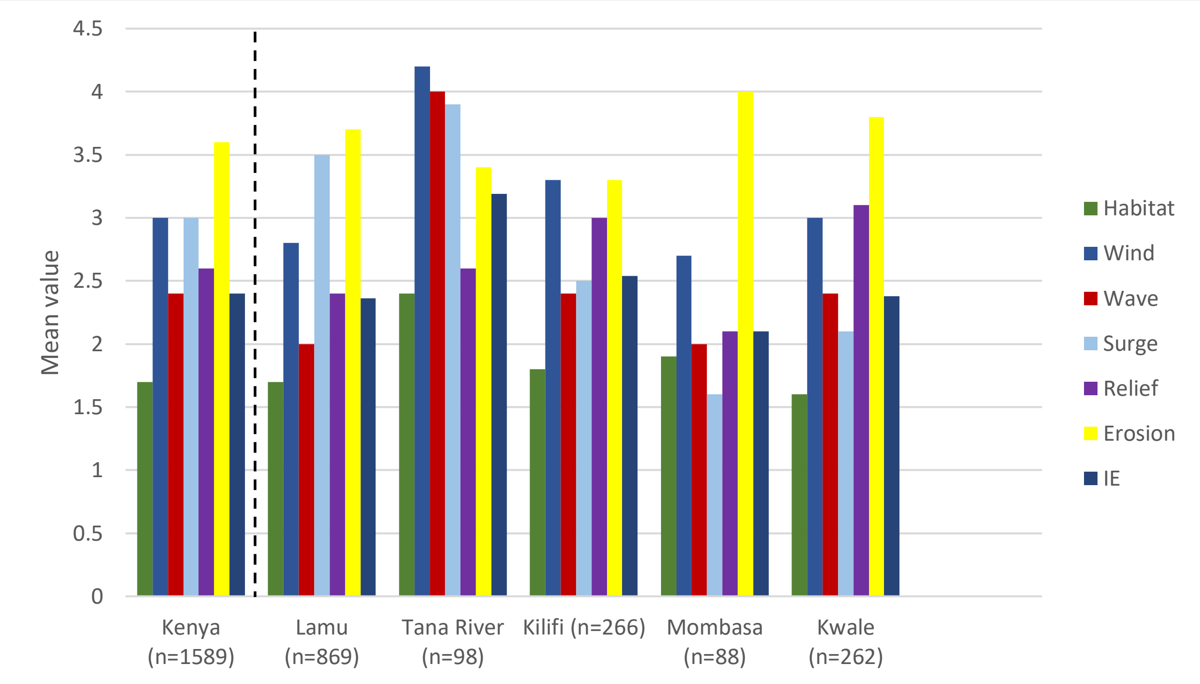

Figure 4.9: Mean values of coastal exposure indicators per county

Coastal exposure in Lamu county

Currently, 10% of Lamu county's shoreline is at a higher level of exposure with the most exposed area being Lamu Island has 28% of its shore at a higher level of exposure. Manda and Pate Islands both have 17% of their shoreline at a higher level of exposure, Ndau Island at 16%, and Mainland Lamu at 14%. Basuba and Kinga areas are the least exposed with less than 10% of their shoreline at higher levels of exposure (Figure 4.10).

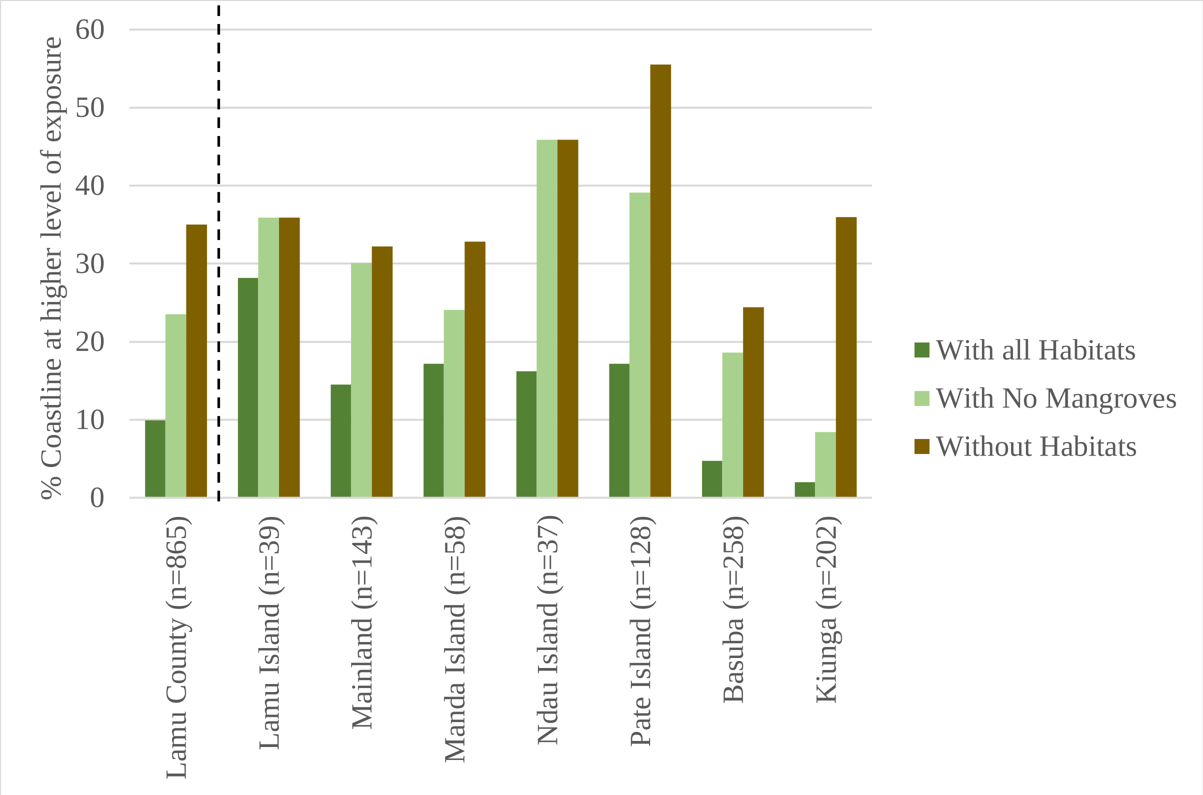

Figure 4.10: Proportion of Lamu county's Coastline at higher levels of exposure

The loss of habitats including mangroves increases the proportion of shoreline length in Lamu county which is at higher exposure levels from 10% to 35% (Figure 4.11). The loss of all habitats in Pate Island will increase the proportion of the shoreline at higher exposure levels from 17% to 56%. All other areas in Lamu county have less than 50% of their shoreline at higher exposure levels. In Ndau and Lamu Islands, mangroves are the only habitat offering protection. Kiunga is the area with lower exposure, where the loss of mangroves results in the shoreline length at higher exposure increasing from 2% to 8%. The greatest relative increase in the proportion of shoreline at higher exposure due to loss of all habitats is expected in Kiunga, a change from 2% to 36% (18 times increase).

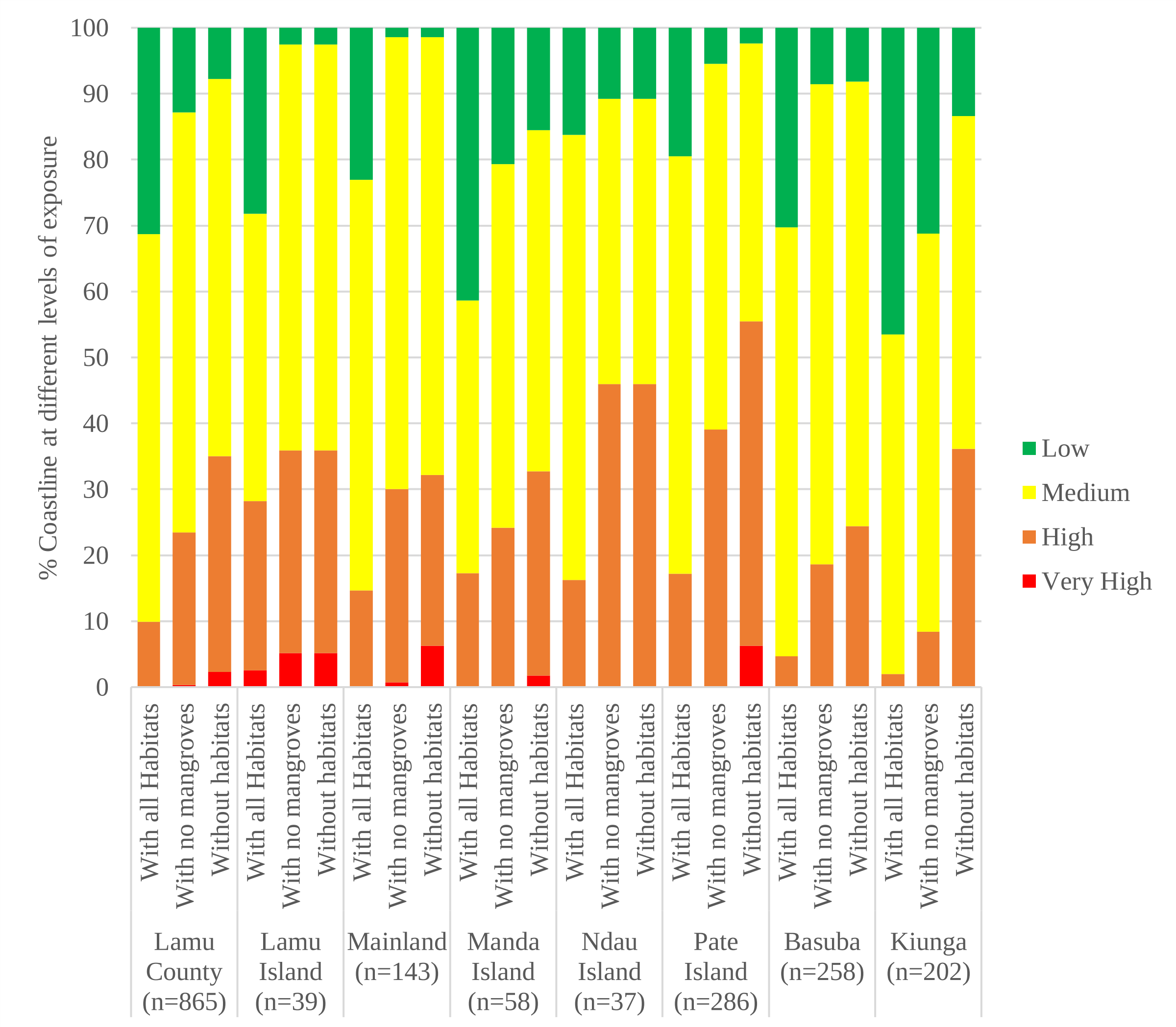

Figure 4.11: Proportion of Lamu county's coastline at various levels of exposure

4.4 Discussion

4.4.1 Mangrove cover change

The analysis of mangrove cover in Kenya indicates that estimates differ depending on the source. The lowest mangrove cover is reported from the CGMFC-21 dataset estimated at 23,003 ha in 2014, while GoK and GMW present more comparable estimates of mangrove cover in 2015, 59,883 ha and 52,902 ha, respectively. Kirui et al. (2013) reported 45,590 ha of mangrove cover in Kenya in 2010. The inconsistencies observed when using global land cover data for local studies have been recognized elsewhere (Giri et al. 2011; Congalton et al. 2014; Xu et al. 2022). These inconsistencies are, amongst other things, due to the use of different remote sensing devices, or different methods of image classification (Xu et al. 2022). As such global datasets of land cover were not designed to be comparable and should be used and observed as independent datasets (Herold et al. 2008).

All analysed data sources indicate a trend of mangrove loss in Kenya, ranging from 0.01% to 0.15% per year. This is a slower rate than the 0.7% per year loss reported by Kirui et al. (2013) between 1985 and 2010. However, Kirui et al. (2013) also reported that rates of mangrove loss were higher in the period 1985-2000, and then decreased to 0.28% between 2000 and 2010. This rate of mangrove loss in Kenya is comparatively smaller than that reported for other areas of the world (Giri et al. 2007; Hamilton and Casey 2016; Jones et al. 2016). For example, the annual rate of mangrove loss in Indonesia was reported to be 0.3% between 2000 to 2012 (Hamilton and Casey 2016) and in Madagascar recorded an annual loss of 1% was recorded between 1990 to 2010 (Jones et al. 2016). The causes of these higher rates of mangrove loss in most areas in Asia are often linked to industrial aquaculture/agriculture activities which were introduced to enhance food security in this part of the world (Richards and Friess 2016). Aquaculture activities in the mangrove areas in Kenya are not practised at a large scale, creating less pressure on the mangrove ecosystem.

The dataset by KMFRI for 2010 and 2019 on Lamu county, shows that the county has lost 31.9 ha of mangrove forests between 2010 and 2019. This translates to an annual loss of 0.01%. The recorded loss is lower than that reported by Kairo et al. (2021) within the same period (1,029 ha), but both sources identify mangrove loss. The rates of mangrove loss in Lamu county, although varying, seems to be much lower than that reported in other areas in Kenya, such as 0.8% per annum between 1969 and 1989 reported in Mida Creek (Alemayehu et al. 2014), 0.7% per annum between 1986 and 2016 in Vanga (Mungai et al. 2019), and 5.1% and 2.7% per annum between 1992 to 2009 in Mombasa for Tudor and Mwache, respectively (Bosire et al. 2014). All these studies have noted similar causes of degradation as those reported in areas in Lamu county including overexploitation of wood products mainly for fuel and construction. The result suggests that the threats are less pronounced in Lamu county probably because most of the mangrove areas in the county are in a rural setting hence suffer less pressure when compared to peri-urban areas like Mombasa. According to Bosire et al. (2014), urban areas in Mombasa recorded great losses of mangrove due to illegal encroachment in the mangrove areas which increased the exploitation of wood for fuel. In addition, sedimentation due to poor land use upstream and domestic sewage pollution (Mohamed et al. 2009) has contributed to the significance loss observed in the urban areas of Mombasa.

Pate and Ndau Islands have recorded the highest net loss in mangroves. This result contradicts the community perceptions where a large per cent of the respondents indicate an increase in cover and no change for Pate and Ndau Islands, respectively. These perceptions were linked to fear of further restrictions on mangrove use which will jeopardise community livelihood (Chapter 3). On the other hand, Lamu mainland and Manda Island have recorded a net gain. These results suggest that reforestation activities in Manda Island and conservation awareness programmes in Mainland Lamu (discussed later in chapter 5 of this thesis) might have played a role in this. The highest rate of mangrove cover change has been recorded within the first 500 metres of human settlements, where human activities are more intense, as also highlighted in other locations in coastal Kenya (Bosire et al. 2014; Mungai et al. 2019; Kairo et al. 2021) suggesting that anthropogenic activity contributes to mangrove change in Lamu county. The increase in rates of mangrove cover changes at 4 to 5 km distance from settlements may be linked to access routes (possibly by boats) to areas of better-quality mangroves that are further away from settlements and closer to the coastline. Mangroves exhibit zonation of species in an upward shore direction with species mostly preferred by locals (e.g., *Sonneratia alba*, *Rhizophora mucronata* and *Ceriops tagal* as discussed in Chapters 2 and 3) being found seaward (Ruwa 1993).

4.4.2 Implication to ecosystem services

Information on the extent of mangrove cover is important in understanding the ability of an ecosystem to provide essential services (Donato et al. 2011; Lee et al. 2014). A lower proportion of the Kenyan coastline is at a higher level of exposure to coastal hazards when compared with other places in the Western Indian Ocean region, such as Mozambique and Madagascar (Ballesteros and Esteves 2021). However, based on the results of this study, the loss of coastal ecosystems in Kenya would increase the proportion of the shoreline experiencing a higher level of exposure to natural hazards from 16% to 41%, similar to the findings of Ballesteros and Esteves (2021). These authors indicated that Kenya benefits the most from the natural coastal protection offered by coastal ecosystems compared to other countries in East Africa such as Mozambique, Madagascar, and Tanzania.

Furthermore, results from this research indicate that corals are the most significant coastal ecosystem in protecting Kenya against exposure to coastal erosion. The proportion of the Kenyan coastline at a higher level of exposure is increased from 16% to 28% with the loss of corals, to 25% with the loss of mangroves, and no change is observed with the loss of seagrasses. At the county level, coral reefs are most significant in protecting the coastline from erosion in Kilifi and Mombasa counties, and mangroves are the most important in Lamu and Tana River counties. These results indicate the importance of prioritising habitats for coastal defence also emphasised in Arkema et al. (2013). In addition, identifying which shoreline is at risk of exposure can provide guidelines for policymakers planning and designing future development along the coastline (Onat et al. 2018; Ballesteros and Esteves 2021).

The analysis of the average IE allows for comparison of the results across the country and at the county level and helps in understanding the contribution of different indicators to the average IE. The highest average IE is observed in Tana River county (3.2) which also has the highest coastline (71%) under higher levels of exposure. The second most impacted county is Kilifi, with 19% of its coastline under higher exposure levels and with the second-highest average IE (2.5). Both these counties have wind as the dominating indicator. The second most significant indicator is wave and erosion for Tana River and Kilifi county, respectively. Tana River is a low-lying delta, suggesting that its geomorphology allows for wind, waves, and surges to significantly contribute to the average IE. Lamu county, on the other hand, has erosion and surge as the strongest contributor to the average IE (2.4). Due to the presence of Islands, this county may have several shoreline points that are more sheltered from waves (as some coastal parts of the Islands are not facing the open sea) thus influencing the relative importance of wind and waves to average exposure values.

Lamu county shows the second-lowest ranking for the natural habitats indicator hence contributing to lowering the average IE, with mangroves shown to contribute the most. Mangroves serve as barriers to wind, waves, and storm surges (Barbier et al. 2011); therefore, preserving mangroves can reduce exposure to coastal hazards (Alongi 2008; Spalding et al. 2014). Countries within the Western

Indian Ocean are susceptible to cyclones and extreme weather events (Mavume et al. 2009; Fitchett and Grab 2014). Climate change impacts, such as increased sea-level rise, can be a threat to the low-lying ecosystem such as mangroves (Nicholls and Cazenave 2010), reducing their effectiveness in providing coastal defence against storms and extreme weather events (McIvor et al. 2015). Incorporating ecosystem base management into disaster risk management policies can reduce impacts on coastal people and infrastructure (Romañach et al. 2018).

Although the contribution of mangroves to the livelihood of the local community has been recognized and emphasised in Chapter 3, their exploitation can increase coastal exposure if not adequately managed. Accurate monitoring of land cover change can better inform policy on habitat loss and contribute to better management decisions to conserve valuable ecosystems (Friess and Webb 2011). Global datasets do not offer insights into the health of mangroves (Hamilton and Casey 2016; Younes Cárdenas et al. 2017) and this limitation is not addressed in the assessment produced using the InVEST model. Considering the health of mangroves is important to better inform planning and decision-making (Bevacqua et al. 2018; Maanan et al. 2018). Future work should focus on addressing the scarcity of data on the state of mangroves worldwide and how this information can be used to assess the effect of mangrove degradation on the provision of ecosystem services.

4.5 Conclusions

This chapter provides an overview of the extent and change in mangrove cover in Kenya during different periods. It also outlines the implication of the loss of mangroves on the provision of the ecosystem service of natural coastal protection. The study indicates that mangrove forests in Kenya are being lost at rates ranging from 0.01 to 0.15% per annum. Further, the results show that 16% of the Kenyan coastline is at higher levels of exposure to natural hazards and this can increase to 41% if coastal ecosystems (mangroves, seagrasses and coral reefs) are lost. Tana River county is identified as the most exposed county, as it benefits the least from natural coastal protection. counties of Kilifi, Kwale and Lamu are benefiting the most from coastal habitats as the proportion of their shorelines at higher levels of exposure is increased most with the absence of habitats.

Lamu county has recorded an annual loss of 0.01% per annum of mangrove cover. Mangrove cover change in this county is varying with some areas indicating gain and other areas a loss but showing higher changes closer to settlements. The study has estimated where mangroves in Lamu county are reducing exposure to coastal hazards. Results indicate that 14% of the county's shoreline is likely to show higher levels of exposure if mangroves are lost. Nevertheless, careful consideration in the interpretation of the results is required as the model does not take into consideration the health state of the mangroves. In addition, to the importance of mangroves to local livelihoods identified in Chapter 3, the information presented here points out where mangrove conservation is more likely to reduce exposure to coastal hazards in Kenya and Lamu county and should be prioritised for monitoring and management measures.

5 Adaptation options for mangrove users in Kenya

5.1 Introduction

Human adaptation to climate change concerning food security and ecosystem health has recently gained concern in international policies (Adger et al. 2009). Participatory processes can enhance the uptake of adaptation and mitigation findings within vulnerable communities and improve governance (van Aalst et al. 2008). A participatory approach allows for the understanding of knowledge and perspective of different stakeholders, and this is a key principle of adaptation planning (Ellison 2014).

Adaptation strategies on agro-ecosystems geared to reduce vulnerability to climate change exhibit different forms including structural; technical (irrigation), management-related (Capacity building/water management), regulatory measures, and economic measures (Livelihood diversification) among others (Boomiraj et al. 2010; Bastakoti et al. 2017). Using a revised DPSIR framework to analyse adaptation options showed that both top-down (e.g., statutory regulation levies) and bottom-up approaches (community-based partnerships and PES schemes) can be effective (Brown and Everard 2015). As for climate change adaptation related to mangrove ecosystems, studies, most often mention improved resource management measures, including: establishing protected areas, rehabilitation of degraded mangrove areas, education and awareness, monitoring, and networking, improved legislation that facilitates mangrove protection and sustained use; and proactive planning for changed conditions (Gilman et al. 2008; Ellison 2014).

Although general knowledge and recognition of the role of mangrove forests in climate change mitigations are improving in Kenya (Lang'at et al. 2021), decision-makers need a better understanding of how mangroves are changing, the effects on traditional ways of living, and how adaptation options can reduce impacts on both the communities and the ecosystem (Nelson et al. 2007). However, the limited information on the mangrove use impacts has not been well documented and has threatened most of the management and policy strategies under implementation or monitoring. Chapter 3 identified variations in the perception of changes across locations in Lamu county, highlighting the need to tailor engagement and management approaches, including adaptation. Bastakoti et al. (2017) noted differences in adaptation measures in coping with drought across locations in Nepal. For instance, communities living upstream of Koshi river flood plains in China have developed both structural and economic measures (e.g. crop livelihood diversification and seasonal migration) while those living downstream have only non-structural measures e.g. dyke and water control styructuresformation of a water management committee (Bastakoti et al. 2017). In addition to climatic effects, population, poverty, and unequal access to resources have proven to increase the vulnerability of the system to climate change and affect the adaptive capacity of the system (Boomiraj et al. 2010).

Studies have shown that adaptation depends on external circumstances such as the availability and feasibility of measures, and capital (Koerth et al. 2013). A framework guiding the sustainable use of mangroves exists in Kenya (GoK 2017) but does not capture community needs. Identifying adaptation options being implemented in a particular area together with the needs and gaps enhances the improvement of adaptation practices and support for adaptation (Ifejika Speranza and Scholz 2013). This chapter presents the co-creation of a framework that offers practical guidance to support local adaptation for the sustainable use of mangroves sensitive to and inclusive of the cultural identity of coastal communities that traditionally have depended on mangroves The development of the framework involved meetings and focus groups with local stakeholders to achieve the following objectives:

a. to identify issues and adaptation measures that are in place in Lamu county through consultations;
b. to devise adaptation strategies that minimize the social and cultural effects resulting from changes in mangrove forests;
c. to identify implementers for the proposed solutions;
d. to increment and validate the framework considering similarities and differences in issues and adaptation options from other mangrove areas along the Kenyan Coast.

5.2 Methods

The co-creation of the framework for local adaptation involved four steps as indicated in the objectives, achieved following the methods of data collection and analysis summarised in Figure 5.1. The data collection followed the Economic and Social Research Council’s framework for research ethics and ethical approval was granted (ID 32899) by Bournemouth University in compliance with its Code of Research Practice (2019-20) and Research Ethics Code of Practice (2020).

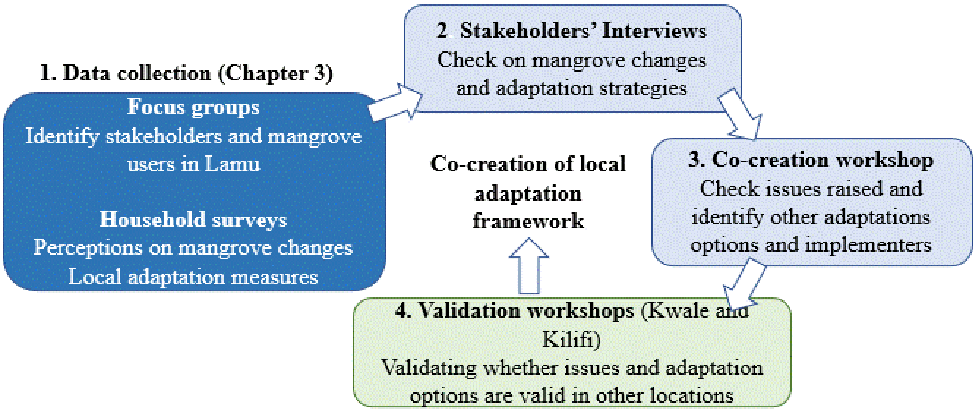

Figure 5.1: Steps that were taken in the development of the framework

5.2.1 Data collection of community perceptions

First, key stakeholders relevant to the use and management of mangrove resources and the local communities to be surveyed were identified during focus groups with local leaders. The perceptions of coastal communities in Lamu County on the factors influencing the state of mangroves and how they have adapted to changes were obtained through household surveys. The focus groups and household surveys are explained in Chapter 3 (Section 3.2.2-*Household survey*).

5.2.2 Interviews with stakeholders

The second step involved interviews with the relevant stakeholders to discuss the relevance of data obtained from the household surveys and add information about adaptation options that were not captured in the survey (e.g. implemented by government and other organisations). A draft framework was then produced identifying the drivers of change and the current and future management responses at the individual, community, and government levels.

Semi-structured interviews were conducted with ten key stakeholders from the government, civil organizations, and community representatives in July 2020. Requests to participate in an interview and the preferred date, time, and format (e.g. phone call or zoom meeting) were sent via email or through a phone call. The invitation was accepted by two officers from Kenya Forest Services (KFS), one from Kenya Fisheries Service (KeFs), two from non-governmental organisations (The Nature Conservancy and Northland Rangeland Trust, NRT), and five community representatives from Lamu, Ndau, Kizingitini, Faza, and Kiunga. The interviews were conducted in English and/or Swahili and lasted for 30 to 45 minutes. The interviews focused on the five major drivers of changes in mangrove areas identified by respondents of the household survey; existing adaptation strategies; other potential adaptations; and whether there were any gaps of information not captured by the survey (Appendix IV for the interview question).

Transcription of the interview recordings was done immediately after the interview. The researcher went through the notes taken during the interview while noting ideas about a topic emerging from the text. Information gathered from these notes was accumulated as the interviews progressed until all 10 participants were interviewed. The researcher went through the notes to formalize them into categories and codes which were included in the workshop discussion material. The notes were read, scrutinized and recurring themes identified.

5.2.3 Co-creation and validation workshops

The third step consisted of a co-creation workshop organized with mangrove users in Lamu county to verify that all key issues and existing and potential adaptations were adequately captured in the draft framework. Additionally, workshop participants were asked to identify the key players in the implementation of adaptation strategies and the viability of alternative adaptation options. The one-day workshop was held in Lamu (28th July 2020) and was attended by 16 participants from organisations that represent key players related to research on mangroves (KMFRI), forest and environmental management (KFS, Kenya Forestry Research Institute (KEFRI), National Environment Management Authority (NEMA), NRT, local participatory management (Lamu county Fisheries, Beach Management Units (BMUs), Community Forest Associations (CFAs), Community Based Organisations (CBOs), and local community representatives. The input received was used to revise the framework. At this stage, the framework represented the existing and potential adaptation options identified for Lamu county.

To check if the framework was representative and valid for other mangrove areas in Kenya, validation workshops were organised with stakeholders in Kilifi (2nd

June 2021) and Kwale (16th June 2021) counties. The Kilifi and Kwale county workshops were attended by 17 and 16 participants, respectively, from CBOs and local NGOs. The meetings followed the government COVID-19 regulations on the number of participants, social distancing, and measures to minimise the spread of the virus at that time.

Each workshop lasted four hours and included presentations, plenary, and group work sessions (Table 5.1). After introductions, participants were divided into groups to discuss changes in mangrove forests and adaptation options. The workshop was concluded with the groups' rapporteurs presenting on outcomes of their deliberations and allowing other workshop participants to refine their contributions.

Table 5.1: Workshop activities and the purpose of each session

Session	**Length**	**purpose**
Introductions	60 minutes	Personal introductions Introduction to workshop objective and goals Research background (purpose and use)
Group work	90 minutes	Identify issues happening in mangrove areas (Kwale and Kilifi county) and deliberate on identified issues presented (Lamu county) Identify/discuss current and future adaptation strategies for specified issues Identify implementation and implementers for each proposed strategy
Feedback	90 minutes	Present outcomes of group deliberations to participants Refine inputs based on the contributions of other participants

5.3 Results

Locals in Lamu, Kilifi and Kwale county identified common issues and some that were site-specific (Table 5.2). Strategies employed to cope with the common issues differed across sites.

Table 5.2: Common and specific adaptation strategies in place to address the issues raised

Issue	Type of adaptation in place	Area identified
Common Issues		
Overharvesting of mangrove wood/ Deforestation	Planting	Lamu, Kilifi, Kwale
	Creating awareness	Lamu, Kilifi, Kwale
	Nursery establishments	Lamu, Kilifi
	Natural regeneration	Lamu
	Use of cement in construction	Lamu
	Encourage fast-growing species	Lamu
	Using LPG cooking gas	Lamu
	Community patrol	Kilifi
	Crab cages in mangroves	Kilifi
	Alternative sources of wood- terrestrial species	Kilifi
	Reporting known cutters to authority	Kilifi
	Alternative income sources (beekeeping, ecotourism)	Kilifi
	Ban on logging	Kilifi
	Surveillance	Kwale
	Use of bricks, cement, and stones in construction	Kwale
	Use of fibre boats	Kwale
	Use of energy-saving stoves in cooking	Kwale
Illegal harvesting	Creating awareness	Kilifi
	Reporting of illegal activities	Kilifi
	Ban on mangrove harvesting	Kwale
	Scout patrols	Kwale
Unsustainable fishing practices	Awareness creation	Kilifi, Kwale
	Patrols / surveillance	Kilifi, Kwale
	Reporting offenders	Kilifi
	Policies	Kilifi
	Use of appropriate fishing gears	Kilifi
	Enforcement of policies	Kilifi
	Vetting fishers	Kwale
	Setting aside an area for anchoring boats	Kwale
Charcoal production	Provision of fast-growing trees	Kilifi
	Awareness creation	Kilifi
	KFS arresting culprits	Kwale
Herbivory and/or predation	Fencing	Kilifi
	Awareness creation	Kilifi, Kwale
Land reclamation and infrastructure development	Supporting restoration	Lamu
	No intervention	Kwale
	Training communities on best practices	Kilifi

Issue	Type of adaptation in place	Area identified
Common Issues		
Climate /environmental changes /Sea level rise	Creating awareness of climate change	Kwale
Sedimentation (due to dredging)	None	Lamu
Sedimentation (damming upstream)	Building gabions	Kwale
Specific to Lamu county		
Use of power saw	Community and KFS surveillance	
Harvesting restrictions	None	
Ban on mangrove harvesting	Alternative livelihoods (farming and fishing)	
Land reclamation and infrastructure development	Supporting restoration	
El Niño	Natural recovery	
Specific to Kilifi county		
Fail restoration	Creating awareness of restoration practices	
Issues relating to CBOs	Creating awareness	
Specific to Kwale county		
Floods	No intervention	
Lightning	Reports to KFS	
Pollution	Regular clean-up campaigns, organised garbage collection, recycling, creating awareness, constructing public toilets	
Encroachment in mangrove areas	Creating awareness, KFS	
Honey harvesting (fire outbreaks)	Surveillance	
Sea sand harvesting	Use of alternatives e.g., *zege* (mixture of cement and stones)	

5.3.1 Issues and adaptation options in Lamu county

In Lamu County, seven key issues hindering the sustainable use of mangrove resources were identified: (1) overharvesting of mangrove wood for fuel (Manda and Pate Islands); (2) use of power saws (Kizingitini and Mkunumbi); (3) harvesting restrictions (Ndau Island and Kiunga); (4) the ban on mangrove harvesting; (5) land reclamation and infrastructure development; (6) sedimentation issues (dredging); and (7) *El Niño* (Mbilingi – Mkunumbi) (Appendix V Consultation workshop matrix presenting adaptation strategies and implementation for identified issues in mangrove forests of Lamu county).

The use of mangrove wood as fuel in the production of lime is currently an illegal activity in Kenya. People prefer to use mangrove wood first because of its accessibility as the kilns are in mangrove areas and secondly due to its high calorific energy. The discussions revealed the reduction in the use of lime for construction as some local communities are currently using cement instead of lime. Efforts for mangrove restorations have also been mentioned to be taking place in areas where degradation had occurred. Other strategies identified include: planting fast-growing species such as *Casuarina* and neem to reduce pressure on mangrove use; advocating for use of cement, and considering the use of modern technology (electricity) in lime production. The latter is an expensive option hence requiring interventions from other partners.

Mangrove harvesting has advanced using traditional extraction methods involving a handheld saw. The use of power saws in mangrove harvest is illegal in Kenya. The market for mangrove wood has been driven by the demand for specific diameter classes (below 13 cm) that are not viable to be cut using a power saw. With the depletion of these size classes, the harvesters have targeted larger trees necessitating the use of power saws. Community efforts in surveillance have been noted in some areas. The proposed action is to increase surveillance against illegal practices and work to make the market sustainable.

Mangrove management has been the responsibility of KFS either singly, or in partnership with the KWS when they occur in the Marine Protected Areas (MPA). These institutions have a different ideology regarding management, where KFS is promoting sustainable utilization and KWS for total protection. Some areas in Lamu county have been closed to community access. The stakeholders proposed the development of harvest guidelines for the area and suggestions to involve the community in management. The latter requires the formation of community forest associations and the development of forest management agreements.

KFS introduced a periodic ban on mangrove logging to regulate the removal of wood products (Chapter 1). The ban has affected local livelihoods and more so those dependent on mangrove wood products. The ban has reportedly led to an increase in crime rates (e.g theft cases, drug use) in the areas. The locals have moved to alternative livelihood activities such as farming, fishing, and beekeeping during the period of the ban. The need to strengthen and empower local communities on other alternative livelihood options e.g seaweed farming to reduce dependency on mangroves was noted during the interviews. Together with the development and strengthening of the existing CFA in Lamu, the development of the PES project was identified as a potential strategy for the conservation of mangroves. Already proposals to set aside mangrove areas for carbon offset projects have been made. As an alternative to cooking, LPG was proposed in Lamu county and hence the need to create awareness and subsidise the commodity.

Development activities in mangrove areas (e.g. the Lamu port construction) have had an impact on the mangrove forests and the users. Dredging works have caused sedimentation into the mangrove areas causing loss of mangroves. Although compensation was made to KFS, there have been claims of failures to support restoration/conservation efforts initiated by communities. Proposals to channel part of the compensation funds to conservation activities were raised. Besides, EIA should be undertaken and environmental management plans to be adhered to in the future, as well as the promotion of industry best practices as opposed to the destructive pattern that has caused sedimentation into mangroves. Some areas in the county, e.g. Mbilingi in Mkunumbi were identified as areas massively affected by *El Niño* 1997-1998. Although there is evidence of natural recovery in the area, the need of improving water storage where available or to construct water storage structures along water pathways was raised.

5.3.2 Issues and adaptation options in Kilifi county

The consultation workshop in Kilifi identified eight issues in mangrove forests in the area (Appendix VI - consultation workshop matrix presenting adaptation strategies and implementation for identified issues in mangrove forests of Kilifi county). These issues include overharvesting of mangrove wood, illegal harvesting, unsustainable fishing practices (bait harvesting, poor fishing methods, overfishing), charcoal burning, climate change and other environmental changes, herbivory, fail restoration and issues relating to Community Based Organisations.

Although the ban on mangrove harvesting is still in place in the county, illegal harvesting of mangrove wood leading to over-harvesting is evident. To reduce the impacts of overharvesting, communities undertake campaigns to restore degraded areas. They also undertake patrols in mangrove areas and report mangrove harvesters to authorities. They have established alternative livelihoods including beekeeping, ecotourism as well as crab cage in the mangrove areas. Awareness campaigns to reduce the pressure on mangrove use as well as supporting livelihood activities are required. The development of a carbon offset project was identified as an opportunity needing support from other stakeholders in determining its feasibility. The use of bricks in buildings was identified as an alternative that needed technical support. More patrols are needed and hence the need to employ more staff and fund community scouts.

Participants reported that restoration campaigns failed due to a lack of knowledge (e.g. species planted in unsuitable locations). Relevant stakeholders were called to support community restoration campaigns by providing technical and financial support. Herbivory of mangrove saplings by livestock, monkeys, as well as oysters, is an issue of concern in Kilifi county needing management intervention. Nevertheless, the use of mangrove leaves as feed for livestock was identified as an opportunity that could be developed sustainably. Setting aside *Avicennia* spp. areas to harvest the leaves for animal feed was identified as a possible intervention.

Harvesting of slugworms (digging worms out of the mangrove soils) to be used as bait in the mangrove areas is causing the deaths of mangrove trees in the county. The communities together with other stakeholders have been creating awareness of the impact of bait harvesting and suggesting alternative sources of bait to fishers. The proposed interventions include creating awareness of bait harvesting as well as the effects of poor fishing practices in the mangrove areas. Laws governing bait types need to be enacted and enforced. Communities need to be supported to attract funds to venture into sustainable aquaculture as an alternative livelihood to reduce pressure on the fishing industry. They also require technical support to utilise the deep sea with appropriate fishing gears.

To reduce charcoal production in the mangrove areas, KFS together with CBOs have been doing sensitization campaigns and providing fast-growing trees to be planted on private farms. The introduction of energy-saving stoves to the locals and sensitization on other alternative livelihood options are some of the opportunities identified to reduce the vice.

5.3.3 Issues and adaptation options in Kwale county

The consultation in Kwale county identified fifteen threats to mangrove forests in the area. The issues identified include flooding of River Umba, lightning, climate change/sea level rise, unsustainable fishing practices, pollution, encroachment in the mangrove areas, charcoal production, honey harvesting, herbivory, illegal harvesting, and deforestation (Appendix VII - Consultation workshop matrix presenting adaptation strategies and implementation for identified issues in mangrove forests of Kwale county).

The deforestation cases reported are from harvesting wood for the construction of houses, boats, fish aggregating devices (FADs), and fuel. Some community members have adopted alternatives to these such as the use of boats made from fibre instead of wood, using bricks made from cement and stones for construction, and the adoption of energy-saving stoves for cooking. The stoves were distributed to communities by stakeholders in the areas as a way of testing the impact it has on the health of the users and the reduction in the use of the wood. In addition, the ban on mangrove harvesting together with scout patrols in the area has led to reduced cases of illegal harvesting. As much as there has been continuous awareness creation on the importance of mangroves and a lot of planting campaigns, more efforts need to be adapted to ensure the ecosystem is restored. Some of the proposed interventions include the afforestation of terrestrial trees to be used in place of mangroves, employing more scouts from the community to control illegal harvesting, and increasing the distribution of energy-saving stoves.

Together with the disposal of sewage and human waste in Vanga, pollution from household garbage and oil spills is a threat to mangrove areas in Kwale county. Youth from the area organise house waste collection at a cost which not all can afford. CBOs and other stakeholders organise regular clean-up campaigns during which they create awareness of the importance of digging pit latrines in houses. A local environmental CBO in Vanga in their effort to control pollution they have constructed a public toilet in the area through the support of local NGOs and other government organisation. Proposed strategies to curb pollution included: supporting the construction of pit latrines and septic tanks in the houses, creating awareness of the effect of pollution, managing household waste through the construction of incinerators, and providing incentives to garbage collectors.

There has been a lot of awareness creation on the impacts of unsustainable fishing practices such as the use of seine and monofilament nets, bait harvesting and other destructive fishing methods to mangroves. In addition, fishers are vetted before going to sea and a lot of surveillance/patrols by local BMUs and fisheries officers. Despite these efforts, cases of destructive fishing practices persist. Suggestions to address this issue included: increasing patrols and surveillance, equipping fishers with the right vessels, and providing subsidies to artificial baits in the market.

There has been no intervention for the natural threats encountered in Vanga e.g. floods, disappearing of Islands and lightning. Stakeholders noted the need for research to assess and document the impacts of lighting on mangroves and the loss of small Islands in Vanga. The need to educate the farmers on the impacts of cutting trees and farming on riverbanks to reduce the impacts of floods was raised. Construction of dams to harvest excess water from river Umba during the rainy season to be used during droughts was identified as an opportunity.

Participants identified the need for community involvement in the decision-making about infrastructure developments in Kwale county. The construction of the seawall in Vanga and the jetty at Shimoni lacked the involvement of the locals in decision-making. The proposal is to involve the public in future developments to allow for their opinions to be incorporated regarding environmental conservation and to ensure community projects are supported with any revenue arising from developments. Other activities impacting the mangroves included charcoal production, wild harvesting of honey and herbivory by livestock. The importance of educating the locals on the impacts and opportunities available was noted. Installation of beehives in the mangroves and the use of terrestrial trees for charcoal production are additional proposed interventions.

5.4 Discussion

The study identified common threats to mangroves in all counties (e.g over-harvesting of mangrove wood) and specific threats to an area. Herbivory (by monkeys) was a unique threat to Kilifi, floods and sea-level rise were noted in Kwale and a ban on mangrove harvest was a concern in Lamu county. The threats in Lamu county revolve mostly around the use of mangroves and the developments happening within the mangrove forests. As observed in Chapter 3 and literature, the major economic activity in many areas in Lamu county traditionally has been mangrove harvesting (Idha 1998). The economic activities in Kilifi county are identified as farming and fishing (Okello et al. 2019; Owuor et al. 2019) hence issues related to fisheries and livestock rearing were observed in this county.

Apart from noted differences concerning the key threats, differences were observed in strategies adopted to changes happening in mangrove forests. These differences could be due to the availability of measures. As noted, availability and feasibility of measures are the biggest determinants of adaptation options (Koerth et al. 2013). In Nepal, in trying to adapt to droughts, some communities were able to implement structural measures (e.g. building irrigation infrastructure) while others could not due to a lack of investment capacity (Bastakoti et al. 2017). In addition, while an aspect was a threat in one area it was seen as an opportunity in another. For instance, the ban on mangrove harvest was identified as a major threat in Lamu county and was a strategy that has controlled overharvesting in Kilifi county and illegal harvesting in Kwale county. Locals in Lamu county have shown strong dependence on mangroves to the point that community pressures resulted in the ban on mangrove harvesting being lifted in Lamu county in 2019 while it still exists in other counties (Section 1.5). Hence, in Lamu, the socioeconomic impacts take priority and the ban on mangrove harvesting is seen as a threat to livelihoods. In other locations, ecological or environmental aspects are given greater importance, particularly near conservation areas where mangrove harvesting is more restricted, and a ban is seen as a welcome measure to reduce habitat loss and degradation.

Despite identifying common threats in the mangrove areas e.g., overharvesting of wood products, the study noted locals are employing different strategies to cope with a common issue. A lot of awareness campaigns and community patrols are taking place in Kilifi county, whilst in Lamu county, we see the use of alternatives in construction and cooking. The development of a PES scheme in the mangrove areas in Kwale and the introduction of energy-saving stoves were identified as effective strategies that are keeping the threat under control. PES schemes if used to complement regulations in place and not replace them can be an effective response to changes in the ecosystem (Brown and Everard 2015). The PES projects in Kwale county, operate under the guiding principle of the Forest Act (Section 1.5) where the formation of CFA was a key step that allowed the community to co-manage the forest with KFS.

The introduction of energy-saving stoves to mangrove-dependent communities (as suggested by workshop participants in Kwale) holds great promise for the conservation of mangroves as it uses less wood, overall saves cooking time and produces less smoke (Shastri et al. 2002; Feka et al. 2009). These energy-saving stoves have been adopted and proven to be effective in Asia (Shastri et al. 2002) and elsewhere in Africa (Feka et al. 2009). The use of energy-saving stoves produces less smoke that will help in combating the effect of climate change, a threat identified as needing intervention. In most areas, the introduction of the stove started as a research project to test its effectiveness through collaboration between local and international agencies (Shastri et al. 2002; Jung and Huxham 2018). In India, it started as a government programme, where technologists trained stove builders (entrepreneurs) who later construct stoves in houses on demand for payment (Shastri et al. 2002). Government departments need to partner with other stakeholders and ensure such effective strategies are supported by subsidising the cost.

Stakeholder consultations did not identify solutions to issues related to climate change impacts but suggested creating awareness on impacts as well as urging scientists to research and share information. A link between government agencies to fund and stimulate research to address knowledge gaps is necessary. In addition, the agencies need to develop education campaigns to disseminate the findings. Littell et al. (2012) in their study to develop tools for adaptation, also identified the need for long-term science management partnership and that decision to be based on scientific information when developing adaptation strategies to climate change.

Limited adaptation options are employed by locals along the Kenyan Coast but the study identified opportunities that require technical knowledge and finances. Such challenges have been identified as constraints hindering the adoption of adaptation strategies in Asia (Bastakoti et al. 2017). A range of implementers of proposed adaptation strategies including community and national agencies were identified (Appendices V-VII providing consultation workshop matrix for Lamu, Kilifi and Kwale county). The discussions with local stakeholders and community members further identified the need for a collaborative network to ensure policy and decision-making are well-informed of adaptation options. This is to ensure the sustainability of local livelihoods in the face of climate change and other environmental pressures. Key strategies that were coming out in all the issues identified in this study include education and awareness creation, improved management (e.g. increasing surveillance, law enforcement) as well as the involvement of local communities in mangrove-related issues (e.g. decision making). All these strategies were identified as key adaptation responses by Ellison (2014) to combat unsustained use which reduces the resilience of mangroves to climate change. These strategies have been considered effective adaptation options in the mangrove ecosystem as well (Gilman et al. 2008). The establishment of protected areas was not well received by locals in Lamu county and suggested rotational harvesting instead. On the contrary, Ellison (2014) mentioned the development of community-managed protected areas as a strategy that would build the resilience of the system to climate change.

The literature pointed out that adaptation must be done at the local level while considering local needs (Ellison 2014). The framework developed here has community engagement at heart (Figure 5.2) and can be adapted to assess adaptation needs and alternatives in other contexts and geographical locations. Nevertheless, the quality of the feedback obtained during surveys depends on how consultations are conducted and the composition of the participants. Therefore to avoid bias by considering the local opinions alone, it was important to incorporate the researcher's views as well as consulting literature. In addition, public engagement does not imply that local opinions are the most suitable or sustainable but it offers an opportunity to discuss alternatives and raise awareness. Successful discussions that evolved during the consultations include the suitability of planting suggested terrestrial plants as an alternative to mangrove wood, only those species that were agreed to be suitable after the discussions were listed for adoption e.g. casuarina.

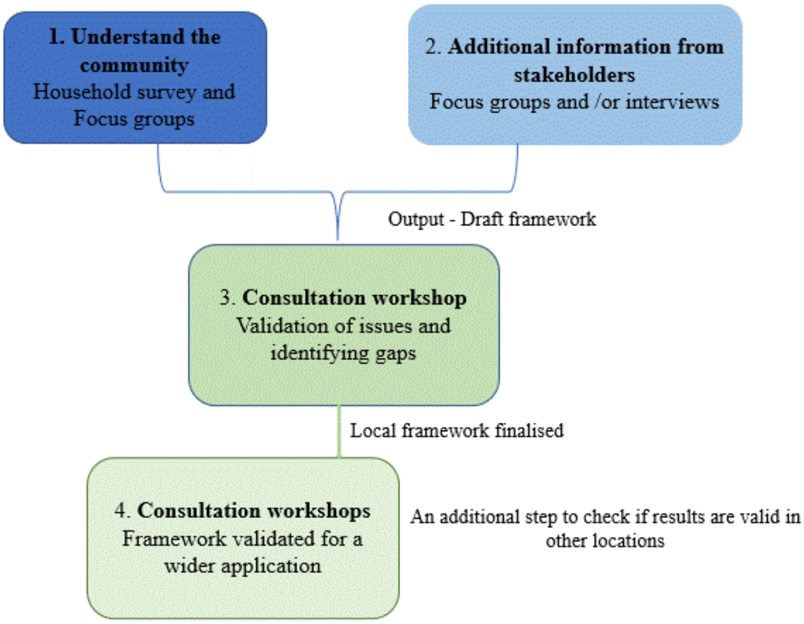

Figure 5.2: A framework to identify adaptation options considering local needs and experiences.

5.5 Conclusion

This study involved consulting stakeholders on issues and adaptation strategies governing mangroves of Lamu, Kilifi and Kwale counties. The study noted differences in the three areas both concerning the key threats identified and the adaptation options employed. Identified threats unique to the areas included a ban on mangrove harvest and land reclamation and infrastructure development in Lamu county, herbivory by livestock and primates in Kilifi county and, floods and sea-level rise in Kwale county. Overharvesting of wood resources was common in all three counties. Nevertheless, the study identified differences in the way communities cope with this common threat. While locals in Lamu county use alternatives such as cement for construction and LPG gas for cooking, Residents in Kilifi mention the use of alternative sources of wood for construction and cooking and in Kwale county the use of bricks in construction and energy-saving stoves for cooking. Awareness campaigns on impacts that come with mangrove destructions are ongoing as well as surveillance and patrols in the mangrove forests. These efforts are from both local communities and the management departments. Some of the proposed strategies to reduce mangrove loss need technical and financial support from stakeholders, including subsidising alternatives for construction and fuel, promoting PES schemes, and initiating and supporting mangrove-related livelihood options. Seasonal and rotational closure of mangrove areas was suggested as a more sustainable option for mangrove conservation than a complete ban on mangrove harvesting in Lamu county. However, the ban on mangrove harvesting was seen as a solution to the overharvesting of wood products in Kilifi county. A partnership between government, researchers and communities was seen as essential in the planning and implementation of adaptation strategies.

6 Conclusions

It is increasingly recognised that adaptation to environmental changes must be devised at the local level, taking into consideration local perceptions and needs while being informed by a wider knowledge of existing practices. This thesis presents an evidence-based framework for mangrove-dependent communities informed by a better understanding of how mangroves are used by coastal communities and how they perceive and respond to changes in mangrove forests. This framework was developed for Lamu county (Northern Kenya) and expanded to cover issues and adaptation options in Kilifi and Kwale counties, also in Kenya. The steps proposed in the framework can be adapted for applications in other locations worldwide and other contexts (e.g., changes in other ecosystems).

The research involved multiple methods that allowed a comprehensive understanding of the uses of mangroves and adaptation measures implemented as a response to changes in mangrove areas required to inform the development of the framework. A systematic literature review identified how mangroves are used by coastal communities worldwide (Chapter 2). A large household survey focusing on Lamu county and focus groups captured local mangrove uses, perceptions of changes happening in local mangrove forests and adaptation experiences (Chapter 3). A GIS-based model was used to assess the effects of mangrove loss in the provision of ecosystem services, focusing on natural coastal protection (Chapter 4). The knowledge obtained from these chapters informed the development of the adaptation framework that identifies opportunities for the sustainable use and management of the mangrove resources described in Chapter 5.

6.1 Key findings

A systematic review of 250 papers on the Web of Science focusing on mangrove uses has shown that 42% of the papers mention mangrove uses in Asia, the continent with the largest mangrove coverage worldwide (40% of the world's mangroves). A total of 11 ecosystem services were identified in the papers, with support and regulation services being the most covered, and cultural services the least. The contribution of mangroves to fisheries is the most researched ecosystem service (42%), followed by the provision of habitat (23%), and the carbon sequestration and storage capacity of mangroves (19%). These three services were mentioned in research covering all the regions. In Asia, research points to the conversion of mangrove areas for aquaculture as a key threat. Although the ecosystem service of coastal protection was covered in only 10% of the articles, it is recognised as the service contributing the most to the total value of mangroves, receiving the most attention in valuation studies. Coastal protection service was covered in all regions except in South America. The use of mangroves in the treatment of waste and purification of water was captured in Asia and South America only. This service was the only one missing in articles from Africa.

The most cited direct uses of mangroves were: wood for fuel and construction (19% and 16% of the articles, respectively); the provision of food and fodder (8%), medicines for different ailments (7%) and tanning/dye (6%). The direct uses of mangrove products were covered in all the regions except in Oceania. The link between commercial harvesting of mangrove wood for fuel and degradation of mangroves was established in Asia, Africa, and South America. A shift is observed in the use of wood from being the main source of income to subsistence use only in these areas to attempt to reduce wood extraction and in the long run, reduce degradation of the mangrove ecosystem.

A systematic review of the literature is useful to identify gaps of knowledge concerning the types of ecosystem services that were studied and the geographical coverage. However, it should not be assumed that the literature gives a fair reflection of the services that are more widely used or valued by local communities. The focus of research can be driven or steered according to funding availability and reflecting wider agendas beyond the needs and reality of mangrove-dependent communities. For example, research presented in this thesis shows that 89% of households interviewed in Lamu county use mangroves, and the most common use is wood products for fuel and construction. Less than 20% of papers found through the systematic review cover the use of mangrove wood.

The regulation and support services recognised by the community followed a similar suit to that identified in the analysis of global literature, as the contribution of mangroves to fisheries was the most recognised (31%), followed by climate regulation (16%), coastal protection (15%) and habitat (8%). Kenya benefits from the natural coastal protection offered by its coastal ecosystems. Currently, only 16% of the country's coastline is at a higher level of exposure to coastal hazards but the loss of corals and mangroves could increase the proportion of the coastline at higher risk of exposure to 41%. Although coral reefs protect slightly more of the country's shoreline against coastal hazards, mangroves contribute the most in Lamu and Tana River counties. With 71% of its shoreline showing higher exposure levels, Tana River is the most exposed county. However, the loss of habitats can increase four times the proportion of Kwale's coastlines at a higher level of exposure and more than double in Kilifi and Lamu. This information is important to inform local communities of the wider importance of mangroves and guide management in prioritizing areas for conservation and monitoring habitat degradation.

Datasets analysed here indicate a small but consistent decrease in mangrove cover in Kenya and Lamu. Contrary to this, most communities in Lamu perceived an increase in mangrove cover in the last decade, although variations were observed depending on respondents' location, gender, and level of education. Perceptions of changes in mangroves are also influenced by the level of dependency, as positive changes are reported by those more directly dependent on the resource (i.e., mangrove harvesters); a bias likely reflecting a fear of jeopardising their main source of income. Understanding the variations in local perceptions is needed to bring information that is tailored and relevant to each group to create awareness more effectively about sustainable practices and address misunderstandings about the state of local mangroves.

Similar to associations suggested in the literature, the overharvesting of resources was identified as the major threat in the three main mangrove areas along the Kenyan Coast (Lamu, Kwale and Kilifi counties) by participants of this research. They identified traditional harvesting methods as sustainable, and the use of a power saw (which is illegal) as a threat. Some other threats identified by workshop participants were unique to their areas, such as herbivory in Kilifi; floods, and pollution in Kwale; and the ban on mangrove logging in Lamu. While the ban on mangrove harvesting was observed to be a positive measure to control the overharvesting of mangrove resources in Kilifi, it was identified as a threat to livelihoods in Lamu county. Applying similar management intervention across locations may not be the best approach and hence the mechanism of management and the timings need to be site-specific, considering the status of local forests, the needs of local people, and the engagement tailored to address local perceptions.

Local communities have developed strategies to cope with changes happening in mangroves. These strategies include the use of alternative sources to wood for construction (e.g., use of cement, bricks, or other types of wood) and fuel (e.g., LPG gas and energy-saving stoves) and changing the main source of livelihood. Adaptation strategies to address common threats differed between counties. Concerning alternatives to mangrove products for construction, locals are switching to cement in Lamu county, bricks in Kwale, and wood from other species of trees in Kilifi. As alternatives to mangrove wood for fuel in cooking, LPG gas has been used in Lamu, other sources of wood in Kilifi and energy-saving stoves in Kwale county. To reduce mangrove degradation, participants reported restoration activities, patrol and surveillance in the mangrove areas. Communities have had to move to alternative sources of livelihood such as farming, beekeeping, fishing, and ecotourism.

Most of these strategies are short-term to address current pressures and failed to be embedded within the traditions and culture of the locals. To be culturally sustainable, there is a need to create opportunities for a longer-term switch of main incomes, increase local capacity to undertake new occupations, and raise awareness about the wider indirect importance of mangroves. Some strategies to reduce the use of mangrove wood require technical and/or financial support to stimulate wider uptake. Results from this study indicate that people switch to alternative products when it becomes affordable to them, and this is more frequent with a higher level of education. Improving local levels of education usually, lead to higher incomes and can facilitate capacity building, which together are factors contributing to lower dependency on mangroves. Managers should consider the need for these investments in education and capacity building to achieve longer-term community changes when developing policies and interventions.

This study has developed a framework proving key steps that could be taken to assess communities' adaptation needs and alternatives in other contexts and geographical locations. This framework that had community at heart focused on the mangrove ecosystems, but this sequence could be used in other coastal habitats and other applications.

6.2 Limitations and directions for future research

The importance of combining methodologies to address a research question was proved in this study as findings from one method complemented the findings of the other. Nevertheless, the quality of results depends on how a survey is conducted and the composition of the participants. The stakeholders' workshop in Kwale and

Kilifi involved more environmental groups, reflecting the proximity to mangrove conservation areas. However, this is also a reason for the differences in the main threats and adaptations identified, when compared with Lamu, where mangrove harvesting is still legal. A greater effort to diversify the range of stakeholders could have captured more diverse views in future research. The restrictions to travel and gatherings imposed during the Covid-19 pandemic were important constraints limiting the number of participants and the number of workshops that were feasible at the time this research was undertaken.

Results from this research provide evidence that qualifies the importance of considering resource management and adaptation at the local level, considering local perceptions and needs. The scale of local here implies community level, as important differences were observed in the level of mangrove dependency, perceptions and adaptations. The engagement required to understand variations between communities and to devise and implement adaptation at the local level demands time and effort but might bring greater longer-term benefits. It is important to recognise the importance of research to inform local adaptations of approaches used elsewhere. The role of researchers in the implementation of the framework suggested here for the co-creation of adaptation strategies is important to raise awareness when solutions proposed might be unsuitable (e.g., due to wider potential environmental or social impacts) or to reduce the influence of biased views.

It is recommended that one should consider community diversity in identifying management and adaptation options. Tailoring conservation strategies to particular communities can facilitate the wider and longer-term adoption of adaptation measures that are culturally aware. The role of education in stimulating good practices and changes in attitude cannot be ignored. Including a wider discussion about ecosystem services while emphasising the cultural and intrinsic values of natural ecosystems in schools can lead to improved environmental quality and livelihoods, the underpinning objective of resource management and conservation. The younger generations are fundamental agents for the transition to sustainable resource use and management. Not only the knowledge they gain can establish new long-lasting behaviours that will become the new norms, but they are also vectors of change, transferring knowledge and stimulating change to the wider community.

Dissemination of findings is an important (and overlooked) step integral to the research process. For the research to have any impact, results must be disseminated to end-users widely, particularly to the stakeholders and communities who were directly or indirectly involved in the workshops, interviews, or surveys. An important next step is the creation of more user-friendly material and policy briefs that can be shared with stakeholders and the communities. Community leaders and government organisations could form a partnership to create a pilot adaptation programme for Lamu that uses the knowledge produced in this thesis. The adaptation programme could identify the measures to be prioritised for implementation, timeframes for monitoring progress and impacts and mechanisms of funding and technical support. The framework could then be applied to understand the issues and perceptions in other areas. Further, a database of adaptation options with case studies from around the world that can be easily accessed would be very useful to inform and inspire local communities.

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APPENDICES

Appendix I: Justification for exclusion of articles from the analysis with examples of articles excluded

Reason for exclusion	Article title
Remote sensing / Mapping	Segmenting mangrove ecosystems drone images using SLIC superpixels
	A WebGIS-Based Study for Managing Mangroves of Godavari Wetland, Andhra Pradesh, India
	Mangrove Mapping and Above-Ground Biomass Change Detection using Satellite Images in Coastal Areas of Thai Binh Province, Vietnam
	Understanding Dynamics of Mangrove Forest on Protected Areas of Hainan Island, China: 30 Years of Evidence from Remote Sensing
	Application of Sentinel-2 Multispectral Data for Habitat Mapping of Pacific Islands: Palau Republic (Micronesia, Pacific Ocean)
	Application of Sentinel-2 Multispectral Data for Habitat Mapping of Pacific Islands: Palau Republic (Micronesia, Pacific Ocean)
	Mapping Height and Aboveground Biomass of Mangrove Forests on Hainan Island Using UAV-LiDAR Sampling
Habitat complexity, Structure and productivity	Impact of deforestation on mangrove tree diversity, biomass and community dynamics in the Segara Anakan Lagoon, Java, Indonesia: A ten-year perspective
	Climatic Controls on the Distribution of Foundation Plant Species in Coastal Wetlands of the Conterminous United States: Knowledge Gaps and Emerging Research Needs
	Structural characteristics, above-ground biomass and productivity of mangrove forest situated in areas with different levels of pollution in the Niger Delta, Nigeria
	Classification of Mangrove Species Using Combined WordView-3 and LiDAR Data in Mai Po Nature Reserve, Hong Kong
	Detrital traits affect substitutability of a range-expanding foundation species across latitude
	Responses of soil and plants to spatio-temporal changes in landscape under different land use in Imo watershed, southern Nigeria
	A general framework for propagule dispersal in mangroves
	Microclimate Influences Mangrove Freeze Damage: Implications for Range Expansion in Response to Changing Macroclimate
	Structure and regeneration status of mangrove patches along the estuarine and coastal stretches of Kerala, India

Reason for exclusion	Article title
Land Use Land Cover Changes (LULCC)	Land use-induced change in trophic state of Shenzhen Bay (South China) over the past half-century
	Land-based and climatic stressors of mangrove cover change in the Auckland Region, New Zealand
	The effect of anthropogenic drivers on spatial patterns of mangrove land use on the Amazon coast
	What Happened to the Forests of Sierra Leone?
	Monitoring mangrove forest cover declination at kilim karst geoforest park, Langkawi from 2005 to 2017 using geospatial technology
Analysis of Physicochemical parameters and/ or Biogeochemistry	The Physiochemical Condition of Mangrove Ecosystems in The Coastal District of Sulamo, Kupang, East Nusa Tenggara, Indonesia
	Bioavailability and sequential extraction of mercury in soils and organisms of a mangrove contaminated by a chlor-alkali plant
	Stable isotopes indicate ecosystem restructuring following climate-driven mangrove dieback
	The application of delta C-13, TOC and C/N geochemistry of mangrove sediments to reconstruct Holocene paleoenvironments and relative sea levels, Puerto Rico
	Mangrove Sediment Microbiome: Adaptive Microbial Assemblages and Their Routed Biogeochemical Processes in Yunxiao Mangrove National Nature Reserve, China
Spatial planning and/or Mangrove management	Indonesia Provincial Spatial Plans on mangroves in era of decentralization: Application of content analysis to 27 provinces and blue carbonas overlooked components
	Sustainable Management of Coastal Wetlands in Taiwan: A Review for Invasion, Conservation, and Removal of Mangroves
	Conservation of mangroves in kuala perlis, malaysia-a case study of socio-economic attributes of fishermen driving valuation in sustaining livelihoods through forest management
	Community Perception and Participation of Mangrove Ecosystem in Ngurah Rai Forest Park Bali, Indonesia
	Socio-ecological assessment for environmental planning in coastal fishery areas: A case study in Brazilian mangroves
Pollution	Predicting the exposure of coastal species to plastic pollution in a complex island archipelago
	Organochlorine concentrations in aquatic organisms from different trophic levels of the Sundarbans mangrove ecosystem and their implications for human consumption
	Metals Content In Edible Gastropod From Blanakan Silvofishery Ponds

Reason for exclusion	**Article title**
	Microplastic Contamination on *Cerithidea obtusa* (Lamarck 1822) in Pangkal Babu Mangrove Forest Area, Tanjung Jabung Barat District, Jambi
	Interrogating pollution sources in a mangrove food web using multiple stable isotopes
Impacts of Aquaculture / mariculture / Farming	Is Super-Intensification the Solution to Shrimp Production and Export Sustainability?
	Domestic duck (Anas platyrhynchos) farming in mangrove forests in southern China: Unsustainable and sustainable patterns
	Ecological impact of salt farming in mangroves on the habitat and food sources of *Austruca occidentalis* and *Littoraria subvittata*
Restoration/ rehabilitation	Jump-starting coastal wetland restoration: a comparison of marsh and mangrove foundation species
	Species richness accelerates marine ecosystem restoration in the Coral Triangle
	Mangrove rehabilitation along urban coastlines: A Singapore case study
	Assessing mangrove clearance methods to minimise adverse impacts and maximise the potential to achieve restoration objectives
Genetics	The complete chloroplast genome sequence of *Pemphis acidula* (Lythraceae)
	Genetic population structure of the mangrove snails *Littoraria subvittata* and *L. pallescens* in the Western Indian Ocean
Physiological and /or Biological studies	A general framework for propagule dispersal in mangroves
	Global-scale dispersal and connectivity in mangroves
Archaeology	The sub-fossils of leaf fragments in sediments as an indicator of mangrove development in the Yingluo Bay, Guangxi, Southwest China over the last 130 years
	Mangrove response to sea level rise: palaeoecological insights from macrotidal systems in northern Australia
Experimental studies/Isotope analysis	Utilization of SDS-PAGE and histochemistry for pharmacognostical studies on selected mangroves and halophytes from the Pichavaram, South India
	Carbon isotope fractionation in the mangrove Avicennia marina has implications for food web and blue carbon research
	Mangrove expansion into temperate marshes alters habitat quality for recruiting Callinectes spp.

Appendix II: Publication produced in the framework of the review chapter (Chapter 2)

Hamza, A. J., Esteves, L. S., Cvitanovic, M., and Kairo, J., 2020. Past and Present Utilization of Mangrove Resources in Eastern Africa and Drivers of Change. *Journal of Coastal Research* [online], 95 (sp1), 39. Available from: https://bioone.org/journals/journal-of-coastal-research/volume-95/issue-sp1/SI95-008.1/Past-and-Present-Utilization-of-Mangrove-Resources-in-Eastern-Africa/10.2112/SI95-008.1.full

Appendix III: Questionnaire used for the household survey

Questionnaire No: ______ Date: ____________ Name of Village: ____________

Part I - Demographic traits

1. What is your age range? ☐ 18-24 ☐ 25-29 ☐ 30-34 ☐ 35-39 ☐ 40-49 ☐ 50-59 ☐ 60-69 ☐ over 70
2. What is your biological sex? ☐Male ☐Female ☐Prefer not to say
3. What is your highest education level? ☐No education ☐Incomplete primary ☐Complete primary ☐Incomplete secondary ☐Complete secondary ☐Higher education ☐Madrassa ☐Others, please specify
   ____
4. What is the size of your household? ______________
5. For how many years have you lived in this area? ___________
6. What is your primary Occupation? _________ What is your alternative occupation? __________

Part II - Mangrove use and dependency

1. Do you use mangroves? ☐ Yes ☐ No
2. How do you utilise/obtain mangrove products?
   ☐ Harvest ☐ Buy products ☐Other, Specify ____________________________
3. What do you get from the mangroves?

Product type	Preferred mangrove species	From which part of the plant do you get this product?	For how many years have you been using the product?	Rank products from most to least used (1 – most used)
Construction poles ☐Buy ☐Harvest		☐Flower ☐Fruit ☐Seed ☐Leaf ☐ Twig ☐Bark ☐Wood ☐Tuber /root ☐ Others, please specify ☐		
Fuelwood ☐Buy ☐Harvest		☐Flower ☐Fruit ☐Seed ☐Leaf ☐ Twig ☐Bark ☐Wood ☐Tuber /root ☐ Others, please specify ☐		
Food ☐Buy ☐Harvest		☐Flower ☐Fruit ☐Seed ☐Leaf ☐ Twig ☐Bark ☐Wood ☐Tuber /root ☐ Others, please specify ☐		
Medicine ☐Buy ☐Harvest		☐Flower ☐Fruit ☐Seed ☐Leaf ☐ Twig ☐Bark ☐Wood ☐Tuber /root ☐ Others, please specify ☐		
Wild fish ☐Buy ☐Harvest		☐Flower ☐Fruit ☐Seed ☐Leaf ☐ Twig ☐Bark ☐Wood ☐Tuber /root ☐ Others, please specify ☐		
Farmed fish ☐Buy ☐Harvest		☐Flower ☐Fruit ☐Seed ☐Leaf ☐ Twig ☐Bark ☐Wood ☐Tuber /root ☐ Others, please specify ☐		

☐ Others (Specify) ☐				

4. How often do you get mangrove products? what is the quantity you get and the estimated cost?

Products	Resource use frequency	Quantity of the resource (scores, bundles, Kgs)		Cost per unit in KES
		Harvest	Purchase	
☐Construction poles	☐Daily ☐Weekly ☐Monthly ☐ Annually ☐Other, Specify ☐			
☐Fuelwood	☐Daily ☐Weekly ☐Monthly ☐ Annually ☐Other, Specify ☐			
☐Food/Fodder for livestock	☐Daily ☐Weekly ☐Monthly ☐ Annually ☐Other, Specify ☐			
☐Medicines	☐Daily ☐Weekly ☐Monthly ☐ Annually ☐Other, Specify ☐			
☐Wild fish	☐Daily ☐Weekly ☐Monthly ☐ Annually ☐Other, Specify ☐			
☐Farmed fish	☐Daily ☐Weekly ☐Monthly ☐ Annually ☐Other, Specify ☐			
☐ Others (Specify) ☐	☐Daily ☐Weekly ☐Monthly ☐ Annually ☐Other, Specify ☐			

5. Apart from the products, do you know of any service(s) that mangrove provides to you or people in the village? ☐Yes ☐No ☐I don't Know
6. If yes which are these services?
   ☐Coastal protection ☐Climate regulation/Remove carbon dioxide from atmosphere ☐Support fisheries ☐Habitat for other organisms ☐ Others, please specify

☐

Part III - Perceived changes in the environment

1. Which changes have you noticed in the mangrove forest during your lifetime in this village?

	Increased	Decreased	No change	I don't know
Cover	☐	☐	☐	☐
Density	☐	☐	☐	☐
Height	☐	☐	☐	☐
Mangrove species	☐	☐	☐	☐
Biodiversity	☐	☐	☐	☐

2. What do you think are the main causes of these changes? Please rank them in order of importance (1 = most important) and indicate whether they resulted in positive or negative changes.

Causes	**Rank**	**Negative changes**	**Positive changes**
☐ Logging/wood harvesting			
☐ Agriculture & aquaculture			

☐ Land reclamation			
☐ Residential & commercial development			
☐ Transportation and service corridors			
☐ Fishing & harvesting of other resources			
☐ Energy production and mining			
☐ Sedimentation			
☐ Heavy rainfall			
☐ Reforestation/planting activities			
☐ Sustainable harvesting			
☐ Awareness creation			
☐ Law enforcement (Mangrove ban)			
☐ Others, please specify			

3. How has the accessibility of the mangrove forest changed during your lifetime in this village?
☐Mangrove has become easier to access ☐Mangrove has become difficult to access ☐There has been no change ☐I don't know

Why do you think so?

4. Has the availability of mangrove products changed during your lifetime in this village?
☐Yes ☐No ☐I don't Know

If yes, which of these products and how is the change?

Products	How has the change been
☐Construction poles	☐Increased quantity ☐Decreased quantity ☐No change ☐I don't know
☐Fuelwood	☐Increased quantity ☐Decreased quantity ☐No change ☐I don't know
☐Food/Fodder for livestock	☐Increased quantity ☐Decreased quantity ☐No change ☐I don't know
☐Medicines	☐Increased quantity ☐Decreased quantity ☐No change ☐I don't know
☐Wild fish	☐Increased quantity ☐Decreased quantity ☐No change ☐I don't know
☐Farmed fish	☐Increased quantity ☐Decreased quantity ☐No change ☐I don't know
☐ Others (Specify)	☐Increased quantity ☐Decreased quantity ☐No change ☐I don't know

5. To what extent do you agree or disagree with the following statements

	Strongly disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly agree	I don't Know
Human activity is the main cause of changes in the mangroves.	1	2	3	4	5	☐
Climate change is the main cause of changes in the mangroves.	1	2	3	4	5	☐
Floods are becoming more frequent or more severe and are affecting the mangroves.	1	2	3	4	5	☐
Droughts are becoming more frequent or more severe and are affecting the mangroves.	1	2	3	4	5	☐
Current policy/management is helping the conservation of mangrove resources	1	2	3	4	5	☐
Poor management of mangrove areas is a main cause of concern	1	2	3	4	5	☐

Part IV – Adaptation to changes in the environment

1. What strategies are you doing to adapt to changes in the environment/climate?

☐ Planting mangrove trees ☐Exploring new fishing species/areas/ gears ☐Use of alternative product ☐ Change my main source of income/occupation ☐ No adaptation methods ☐Others, please specify

2. What else can be done to reduce detrimental changes to mangroves?

By you/your family	Your community	The government/other organisations

3. Any other comments?

Thanks for your time and contribution

Appendix IV: Stakeholders' interview questions

Overharvesting (Fuelwood)

1. Is there an alternative to using mangroves for lime production? If yes what is it? Why is it not currently being used? If No why not?
2. Is there a substitute for lime? What is it?
3. What are the alternatives that could be used (for fuel, for construction)?
4. How can we ensure that the alternatives are adopted/applied?
5. What role can the government/NGO/community play in ensuring these alternatives are adopted?
6. Is the natural recovery sufficient in the areas identified or should restoration efforts be put in place to assist recovery?
7. If restoration is necessary, what is needed? Who should be involved and their roles?
8. Has PES been discussed? If not why not? If yes, why has it not been initiated? What is needed to ensure its adoption? What role can the government/NGO/ community play to ensure PES works?

Use of power saw

1. Why are there still cases of the use of a power saw despite it being illegal?
2. What is needed to ensure that the use of a power saw is not practised?
3. What role can the government/NGO/community play in this?

Restricted harvesting

1. Are the local community involved in the management of the forests?
2. If yes how? If not, why not?
3. How can we improve the involvement of the local users in the management of the forest?

Ban on mangrove harvesting

1. What alternatives are there? Are the activities initiated sufficient to support community livelihood?
2. Is there a need to educate the people on the alternatives and the importance of the ban?
3. What could be the role of government/NGO/community in enhancing capacity?

Elnino

1. How can we ensure the information on the likelihood of occurrence reaches the local communities?

Land reclamation and/ sedimentation

1. Are there any planting activities to cover the reclaimed land for port construction?
2. If yes, where? What is the role of the government/NGO/local communities? Who funds? Who are involved?
3. Are there any incentives given to restoration/conservation activities?
4. If yes who are the beneficiaries?
5. If not, has this been considered? What role can the government/NGO play in this?

Conclusion

1. Are there any other important issues that were not captured?
2. What are they?
3. What strategies could be done to reduce the effect?
4. What could be the role of the government/NGO/community?

Appendix V: Consultation workshop matrix presenting adaptation strategies and implementation for identified issues in mangrove forests of Lamu county

Current strategies in place	Future intervention / strategies	Implementation	
		How?	Who?
Issue 1. Overharvesting (e.g., fuel for lime production) (Manda, Pate Island)			
Natural regeneration (Pate Island and Manda)	Enforce and support restoration activities	- Employ more forest guards - locals - Encourage community participation - Ensure no animal/livestock intrusion - Create partnerships – e.g., with communities to establish more nursery beds - Ensure protection of the nursery beds - Sensitization	- Community ranger - KFS - Community groups - BMU - NGOs - County government - CFA
Replanting (Manda and Pate Island, Kiunga, Ndau)	Seasonal closure of mangroves areas to allow for regrowth	- Do a mapping survey to identify areas where nurseries can be established - Enforcement - Introduce alternative livelihood - Diversify employment opportunities	- Conservancies - KFS - Harvesters
Planting terrestrial trees	Promoting the use of alternative products (cement, gas, electricity)	- Sensitization of the alternatives available - Engaging relevant stakeholders e.g., government and industries - Subsidising the cost of alternative products e.g., cement, gas	- Government (national and county) - Private sectors - CBOs - CFA, NGOs - NEMA - County government
Use of cement	Reviewing licensing procedures	- Engage KFS to review the licensing procedure - Review Policy (UNESCO) site demands - Licencing local harvesters - Monitoring and evaluating harvesters/logging	- KFS - Community groups/Conservancies - County government - NEMA

Current strategies in place	Future intervention / strategies	Implementation	
		How?	**Who?**
Issue 1. Overharvesting (e.g., fuel for lime production) (Manda, Pate Island)			
Encourage fast-growing species (casuarina)	Promote PES Schemes as a source of income for conservation and restoration activities	- Undertake feasibility studies for carbon projects - Sensitization - Promote alternative livelihoods	- Government - Community groups/conservancies - Private sectors - Research institutes (KMFRI, KEFRI) - NEMA
Stakeholders' collaboration in nursery establishment	Reduce the use of lime in construction	- Identify the stakeholders - Engage in Current technological innovations - Search for alternative products - Training users - Subsiding the cost of cement	- County government - Research Institutions - NEMA - KFS for licensing purposes - Community groups/conservancies
Creating awareness	Modern technology of making lime (electric)		
Using of LPG cooking gas	Sustaining awareness creations	- Support awareness efforts	All stakeholders
Issue 2. Use of power saw (e.g., Chongoni, Rewa- Kizingitini; Bandari Salama, Ungu, Kizuke – Mkunumbi)			
Community and KFS surveillance	Enhancing the human capacity of mangrove management at all levels (Forest guards, scouts, rangers)	- Empower conservancies to employ more rangers and forest guards. - Enhance collaboration of interagency teams - Fight corruption - Harmonize the policies - Intensify fine on use of power saw	- NGOs - County government
	Enhancing surveillance capacity of mangrove management at all levels. (Boats, fuel)	- Procuring surveillance equipment for communities e.g., fuel, boat - Introduce incentives to communities to increase their willingness to report	- NGOs - County government - KFS

Current strategies in place	Future intervention / strategies	Implementation	
		How?	Who?
Issue 1. Overharvesting (e.g., fuel for lime production) (Manda, Pate Island)			
		- Increase intelligence gathering from the community.	
	Enhance the technical and legal capacity of mangrove management at all levels (Harvesting plans)	- Developing harvesting action plans - Sensitization- what does the law say? - Formation of interagency surveillance	- KFS - Research institutions - NEMA - NGOs - Conservancies - Security agencies - judiciary
	Enhance KFS patrol surveillance	- KFS county office to be supported through equipment and others	- KFS Headquarter - County government
Issue 3. Restricted harvesting (Ndau and Kiunga – Reserve – entire Lamu county)			
None	Involvement of local communities in management through the development of CFA and management plans	- Strengthen the current CFA - Creating more CFA for management - Do mapping of the forests - Harvesting plan to be strictly followed	- KFS - County government - Conservancies - KWS - Researchers
	Provide guidelines on the kind of products to be extracted from the forest and the zones	- Clear procedures harmonized with fewer bureaucracies - Monitoring	- KFS - KWS - Researchers
	Enforcing laws and policies	- Reviewing the current licensing plan	- KFS - Conservancies
Issue 4. Ban on mangrove harvesting			
Alternative livelihoods (Farming, fishing)	Seasonal /rotational closure	- Follow rotational harvesting strictly - Develop new harvesting plans - Development of management plans at the local level - Restriction to tools prescribed for harvesting	- Community groups - KFS - County government - Researchers

Current strategies in place	Future intervention / strategies	Implementation	
		How?	Who?
Issue 1. Overharvesting (e.g., fuel for lime production) (Manda, Pate Island)			
	Support community alternative livelihoods activities (Conference facilities, tourism)	- Finance community groups to establish the alternative livelihood facilities - Educating the community - Sensitization of the alternatives	- NGOs - KFS - County government - Ministry of Tourism
	Create economic incentives that promote more environmentally responsible behaviour and enhance local livelihood	None	None
	Training and Awareness creation	- Supporting awareness creation initiatives - Organize training sessions on alternative livelihoods for the community for - Meetings - Posters, adverts	- NGOs - KFS - County government - National government
	Initiate and support mangrove-related livelihood activities (Beekeeping, fish/prawn/crab farming)	- Support the creation of facilities and marketing - Training/education - Empowerment - Financial support - Provision of expertise - Link the community with projects at the county related to mangrove activities - Support local groups to obtain grants and projects	- NGOs - County government - Research Institutions - KFS - NEMA - Conservancies
Issue 5. Land reclamation and infrastructure development (e.g., Port construction, Manda Bay)			

Current strategies in place	Future intervention / strategies	Implementation	
		How?	Who?
Issue 1. Overharvesting (e.g., fuel for lime production) (Manda, Pate Island)			
Supporting Restorations activities	Fully account for all risks and costs associated with the development	- Subject activities within mangrove areas to EIA - Adhere to EIA - Implement environmental management plans - Compliance monitoring - Natural resource evaluation (worth of mangroves) - Tradeoffs - Identify alternative sources of fuel - Link the market with other premises for maximization - Sensitization- alternative material for construction - Identify opportunities created by the port	- Developers - KFS - NEMA - Private sectors - County government - Fisheries
	Use industrial best practice	- Training relevant stakeholders - Public participation	- NEMA - Private sectors - Conservancies - NGOs - Research Institutions
	Training and employing the affected users	- Supporting the education of the communities - Creating jobs for the communities	- National government – Lamu port - County government - NEMA
Issue 6. Sedimentation (dredging)			
	Providing incentives for conserving and restoring mangroves	- Identify and implement the incentives - Support restoration efforts	- KFDS - NEMA - NGOs

Current strategies in place	Future intervention / strategies	Implementation	
		How?	Who?
Issue 1. Overharvesting (e.g., fuel for lime production) (Manda, Pate Island)			
			- Community - Private sectors - researchers
	Implement an environmental management plan (EMP) for dredging	- Supporting implementation of EMP - Guidelines to be set for dredging - Fall back plans to be created	- NEMA - Private sector - KFS – enforcement - County government - KPA
Issue 7. *El Niño* (Mbilingi – Mkunumbi)			
Natural recovery	Provide early warning systems	- Dissemination of information on time-through e.g., mass media, phones - Sensitization/education on climate change strategies - Collection and sharing of climate change data information sharing system - Creating fallback plans	- Meteorological Department - Mass media - Community - NDMA- (to provide drought early warning signs)
	Improve/construct water storage and drainage system	- Construct water storage structures along water pathways	- Ministry of Agriculture - National government - Ministry of water -
	Physical planning	-	-

Appendix VI: Consultation workshop matrix presenting adaptation strategies and implementation for identified issues in mangrove forests of Kilifi county

Current strategies in place	**Future intervention / strategies**	**Implementation**	
		How?	**Who?**
Issue 1. Overharvesting (Uyombo, Sita, Dongo Kundu)			
Raising tree nursery	Producing ways to reduce pressure	More awareness creation to help reduce pressure	KFS
Restoring degraded areas	Livelihood support	Stakeholders to support activities like beekeeping, fish farming	KWS, KFS, NGOs
Awareness sensitization campaigns	Develop a Carbon offset project	Feasibility assessment of Carbon offset project	Community and other relevant stakeholders
Community patrol	Increase support to communities/ stakeholders protecting the forest	Improve education especially on the benefits/ importance of mangroves incorporate it into the syllabus	Kilifi County Govt (KCG)
Crab cages in mangrove areas		Enhance the development of alternative incomes	Donor agencies
Planting activities/ initiatives by community members/ organizations		Empower existing organizations & CBOs to incentivize community members to join CBO	NGOs
Alternative sources of wood e.g., terrestrial species		Facilitate building CBOs aimed at protecting mangroves	KMFRI
Reporting cutters to relevant authorities (e.g., KFS)		Develop organizations/ increase participation by various organizations/ agencies to contribute to the incomes of CBOs	KFS
Alternative incomes to ease pressure on the forest e.g., beekeeping, ecotourism		Employ community forest guards to boost the protection of the forest since the community members value the forest more compared to non-natives	Arabuko Sokoke Forest Adjacent Dwellers Association (ASFADA)
Ban on logging		Increase patrols	KFS KWS

Issue 2: Illegal harvesting			
Create awareness of the importance of protecting and conserving mangrove forests	Alternative building methods e.g., *makinga* building bricks instead of mangrove poles	Provide technical support in formulating proposals for funding projects in alternative building methods e.g., the use of *makinga* bricks	KMFRI
	Agroforestry e.g., planting casuarina trees as an alternative wood resource to mangroves	Facilitate seedlings for agroforestry	KFS
	Alternative income sources e.g., beekeeping	Allocate funds towards alternative income sources	County government
Continuous reporting on illegal activities taking place in forests	Increase relevant staff in institutions	Employ more staff to patrol the forests every day and night	KFS, KWS
	Support community scouts to increase their commitment	Provide funds to pay community scouts	County government
	Involve local administration e.g., chief	Have a platform where the local authority can be involved in matters related to forest management	KFS
	Scout booths in known harvesting areas	Establish scout booths in areas known for illegal harvesting	KFS, KWS
	Improve community livelihood	Produce a scheme where those who are known illegal cutters are given alternative income sources to keep them away from mangrove forests	County government
Issue 3. Unsustainable fishing practices			
3a: Bait harvesting – slug worms* (Kirepwe, Uyombo, Dongo kundu, Mida, Sita, Magangani) ***** Slugworms (*choo*) are harvested by digging up mangrove roots which eventually leads to the death of mangroves. These slugworms are used as bait (*chambo*) for fishing			
Awareness creation on the impact of fish baits digging	Use of alternative baits e.g., gastropods	Create awareness among the fishers on bait harvesting implication Enforcement/ creation of laws that govern bait types	KWS County government KMFRI KEFRI ASFADA Community
Creating awareness of other sources of baits	Enhance other fishing methods e.g., fish cages.	Provision of financial resources to undertake other fishing modes	KWS County government

			KMFRI KEFRI ASFADA Community
3b: Poor fishing methods e.g., trapping fish in the intertidal areas and destroying mangroves			
KWS patrols Reporting offenders to authorities	Awareness creation	Organise awareness campaigns on the effects of poor fishing practices and the benefits of mangroves	KWS KFS KCG Community
3c: Overfishing – Fishermen moving to mangroves			
New policies to reduce overfishing	Alternative livelihood e.g., Aquaculture	Support communities to develop proposals that can attract funding to venture into aquaculture	KFS KMFRI KWS KEFRI National government Kilifi County Government ASFADA
Use of appropriate fishing gears Enforcement	Enhance deep sea fishing	Provide gears and capacity to utilise the deep sea	
Issue 4: Charcoal burning			
Provision of fast-growing trees to be planted on private farms (Casuarina, Eucalyptus, Arborea, Neem	Energy-saving stoves	Introduce/provide energy-saving stoves to communities	Community KFS KMFRI KWS KEFRI ASFADA
Create awareness	Alternative livelihood options	Sensitize on other alternative livelihood options	
Issue 5: Climate change and other environmental changes e.g., shoreline change have led to alteration of the ecosystem in such a way that some areas no longer support mangrove growth while some new areas have recently been colonized by mangroves			
Training communities on best practices for restoration and conservation activities based on science	Information creation and sharing	Increased research on the effects of climate change Disseminate scientific information on the effects of climate change and the best adaptation and mitigation strategies	KEFRI KMFRI
Issue 6: Herbivory and/or predation			
6a: Herbivory of seedlings by primates e.g., monkeys			
None	Enhanced Management	Management of habitats should be improved to ensure the primates have adequate food sources so that they do not have to come feed on mangroves	KWS

6b: Predation (Oyster infestation on saplings)			
None	Scientific expertise on how to harvest Oysters without damaging the mangrove saplings	Creating awareness of oyster farming and harvesting	KEFRI KMFRI
		Financial resources for oyster rearing activities	County Government
6c: Livestock damage especially goats feeding on young *Avicennia* saplings			
Fencing off areas where the young saplings are being grown	Creating awareness	Community to be trained on how to harvest and dry *Avicennia* and convert it into feed for animals	KFS KEFRI KMFRI Community KCG
Create awareness and educate fellow villages on taking care of the nurseries	Patrols	Increase patrols and noting areas of disturbance, especially livestock disturbance and report to community leaders	KFS
	Set aside areas for harvesting *Avicennia sp* for animal feed	Funding programmes/projects that convert *Avicennia sp* to animal feeds	County government
Issue 7: Fail restoration campaigns			
Creating awareness among CBOs on the right specie for planting	Supporting restoration activities	Financial resources to facilitate restoration activities	KCG
		Training on the right species to plant depending on the environment	KEFRI, KMFRI
		Identifying the best areas for planting	KEFRI, KMFRI, COBEC, KCG
Issue 8: Cross-cutting issues on CBOs			
8a: Conflict between conservationists and the rest of the community whereby conservators face resistance from community members. Some members intentionally sabotage conservation activities i.e., uprooting planted seedlings which frustrates conservation efforts. The 'opposers' do this because they feel the conservation groups deny them access to mangrove forest products such as wood			
Awareness campaigns	Awareness / sensitization	Community members should be sensitized to the benefits of mangroves and the importance of conserving the ecosystem	KFS, KWS, KCG, KMFRI, KEFRI, NGOs
		Efforts to be made to bring on board all opposing parties	
8b. Community members express frustrations on the difficulties faced in registering for the CFA. Some members feel unrepresented in the handling and the development of the CFA			

None	Sensitization	Sensitize members on the rights of the different user groups as well as the processes in developing CFAs	Community, KFS. KCG, KMFRI
	Coordination	Coordinate efforts to bring all community members on board so that CFA matters are not controlled by a selected few	
a. Lack of cooperation among CBOs, each CBO focuses only on their interests			
None	Enhance cooperation	Harmonize and coordinate efforts by CBOs	Community, KFS. KCG, KMFRI
		Have an umbrella body that can bring together all CBOs and improve information sharing as well as sharing of opportunities	
b. Difficulties for the younger generation to join existing CBOs due to issues with member contributions and stringent regulations. This leads to the development of many new groups that have limited chances of success due to a lack of funding			
None	Reforms in CBOs	Improve regulations for existing CBOs so that new members can easily join	Community, CBOs
c. Problems in information-sharing among CBOs. Some CBOs receive a lot of training compared to others, but this information is not shared/ disseminated effectively across all groups			
None	Enhanced information sharing	Adopt strategies to effectively disseminate the latest information to all CBOs and user groups	Community, CBOs, KMFRI, KEFRI, KCG, NGOs
		Increase opportunities for CBOs so that there are more spaces for more CBOs to participate in conservation without feeling threatened	Donor agencies
d. Donor agencies mostly recognize established CBOs that have existed for longer periods e.g., Dabaso and do not engage smaller, newer CBOs			
None	Boost publicity of smaller CBOs	Stakeholders' analysis to map all existing CBOs and engage them adequately	CBOs, Donor agencies, KCG, National government, community

Appendix VII: Consultation workshop matrix presenting adaptation strategies and implementation for identified issues in mangrove forests of Kwale county

Current strategies in place	Future intervention / strategies	Implementation	
		How?	**Who?**
Issue 1: Floods (River Umba) - Causes soil erosion and sediment deposition in mangrove forest			
No intervention apart from relief (food, medicine & blankets)	Education & awareness creation	Educate farmers to stop farming on riverbeds	KFS, WWF, Seacology, County government, National Disaster Risk Management Unit (NDRM), KMFRI, CDA
	Water harvesting (dams)	Develop water harvesting facilities (Dams)	
	Introduce sustainable farming methods	Planting trees on private farms Prevent cutting trees along riverbanks	Ministry of Agriculture KFS National and County government
Issue 2: Lightning (Vanga, Ngoa)			
Report to KFS	Informing the community after weather forecasting and knowing	Research on the right intervention to be put in place	NGOs
Issue 3: Climate change/Sea level rise – loss of small Islands (Ngoa, Kafumbani, Mkokoni, Vanga, Jimbo - Simiju, Bazo, Makombe)			
Awareness creation on climate change	No suggested intervention	Develop interventions to reduce the impacts of Climate change	GoK, NGOs
	Awareness creation	Creating awareness of the impact of human activities on the environment	KFS, KMFRI
		Information sharing	
Issue 4: Unsustainable fishing practices			
4a: Use of seine nets*, Dynamite, monofilament nets*, crab fishing by using prop root, poison)			
Vetting of fishers before going to fish	Laws should be executed	Prosecute those going against the fishing laws	KeFS, BMU, Coast guards, County government, Community
Awareness creation	Provide the right resources for fishers	Equipping the fishers with the right vessels	
Patrols	Patrols	Increase patrols and surveillance	
		Educate communities on the effect of destructive fishing	
*Seine nets destruct corals and seagrass which are interconnected with mangroves and affect mangroves eventually. The residues accumulated by seines mix with sand and are later pushed by waves into the mangrove areas *Monofilament nets disposed of in the ocean end in the mangrove areas resulting in the death of seedlings			
4b: Bait harvesting (Slug worms)			

Awareness creation of the effects	Introduction of alternative baits	Providing subsidies to manufactured/artificial baits to make it feasible for fishers	County and national government KMFRI KeFS NGOs
	Improve fishing methods	Providing fishers with fishing nets and vessels	
Surveillance	Creating awareness	Educating the communities on the effects and alternative	
4c: Boat anchorage in the mangrove areas			
Identification of areas for anchoring boats	Increase efficiency of the identified areas to anchor boat	Provide security for the areas	KeFS County Government NGOs BMU
Proper anchorage (boat hind and rear)		Increase the number of areas for boats	
		Awareness creation	
Issue 5: Pollution in the mangrove areas			
5a: Damping of garbage			
Regular clean-ups	Improve dumping system	Provide tanks for dumping and arrange for collection	National and County government Private companies NGOs
Organised garbage collection by youth		Bins to be provided closer to houses	
Recycling	Partnering with stakeholders	Waste management training at the local houses	
	Waste incinerators	Construct incinerators	
	Incentives	Provide incentives to youth	
5b: Sewerage and human waste			
Awareness creation on digging pit latrines	Proper waste disposal	Digging latrines & septic tanks in their houses	County government Ministry of health
Local CBO (VAJIKI) constructed public toilets			
5c: Oil spills from boats			
None	Creating awareness	Educating on the effect of oil spills on the marine environment	KMFRI and another research organisation
		Research and provide findings of the damage	
Issue 6: Encroachment in the mangrove areas			
Awareness creation	Proper planning	Survey and set up Riparian areas	KFS, County Government
KFS stopped the encroachment and filed cases against the perpetrators	Laws to be properly executed	Law enforcement by prosecuting those breaking laws	
Issue 7: Charcoal production			
KFS arresting culprits	Awareness creation	Educating the charcoal producers on the effects	KFS, KMFRI
	Promote tree planting	Funding planting campaigns	

Issue 8: Honey harvesting (wild harvesting causes burning and felling of mangroves)			
Surveillance	Promote beekeeping	Beehives installation to attract bees	County government
Issue 9: Herbivory by livestock			
Creating awareness of the effect	Zero grazing	Educate locals on zero grazing	County government
Issue 10: Illegal harvesting			
Ban on harvesting	Increase surveillance	Increase the number of scouts	Carbon offset projects (VBF, Mikoko Pamoja)
Scout patrol	Reduce use of mangrove wood	Increase distribution of energy-saving stoves	
Issue 11: Deforestation (Boat construction, house, Fuelwood (fish preservation), construction of Fish Aggregating Devices FADs)			
Creating awareness	Increase awareness	Exchange visits/ benchmarking programmes	KMFRI, WCS, KeFS, County government
Planting	Establishment of alternative tree sources	Woodlot establishment (terrestrial trees)	
		Support planting activities	
Surveillance	Improve forest surveillance	Employ more community forest scouts	KFS
Use of alternatives (fibre boats, cement bricks and stones, energy-saving stoves)	Introduction of improved. technology	Introduce modern fishing technology, fund solar dryers, distribute more energy-saving stoves, make briquettes from coconut or faecal	County government, KeFS
		Educating the community on tree planting on their farms	
Issue 12: Sea sand harvesting			
Use of alternatives e.g., *zege* (mixture of cement and stones)	Provide alternatives	Introduce better technology to communities	NGOs
Issue 13: Sedimentation (damming upstream)			
Building gabions	Reduce sedimentation	Research on the best trees to be planted in affected areas	KMFRI and other research institutions
		Fund construction of gabions for shoreline protection	
Issue 15: infrastructure development (seawall, jet, oil exploration)			
None	Public participation	Allow for the public to participate in decision making	County and national government National Environment Management Authority (NEMA)
		Access to information	
		Support community project implementation	