Kenya Marine and Fisheries Research Institute

Biodiversity and Socio-Economic Assessment of the Lamu Southern Swamp Mangrove Ecosystem

TECHNICAL REPORT

OCTOBER 2024

<u>Funding Agency</u>

Partner Institutions

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Citation:

Okello, J.A., Oketch, F.O., Mwakha V., Mwamburi, S., Muchiri, Z.W., Amondi, L., Ishmael, N., Komu, H. M., Othoo, C.O., Mbatha, A., Vihenda, M., Sirikwa, L.N. (2024). Biodiversity and socioeconomic assessment of Lamu Southern Swamp mangrove ecosystem. Kenya Marine & Fisheries Research Institute, Kenya.

Acknowledgements

We would like to thank the KMFRI field crew, particularly, Dr. Charles Kosore, Mr. Benard Kimathi, Mr. Sammy Kadhengi, Mr. Joseph Kilonzo, Mr. Ezekiel Nyajong, Ms. Sarah Nyambura, and Mr. Seth Muchembi whose skills, hard work and determination steered the successful collection of data and samples. A big thank you to the KMFRI laboratory crew especially Ms. Sarah Anyango and Mr. Isaac Mondesto of the Molecular Biology laboratory; Mr. Joseph Kilonzo, Mr. Alfred Katana, and Ms. Virginia Wangui of the Biological laboratory; and Mr. Ezekiel Nyanjong, Mr. Johnston Mugendi, and Mr. Nicolas Munyia of the Chemistry laboratory for their unwavering support. We also extend our appreciation to Emmanuel K. Kenga and Simeon M. Ndegwa of KEFRI for their skills and support during the field data collection. Special thanks to our reviewers, Dr. Joseph Indo of the County Government of Kwale together with Mr. Raymond Abok and Mr. David Maundu of KFS-Nairobi for their invaluable contributions. Last but not least, we would like to express our utmost gratitude to Wetlands International for funding the project in an effort to enhance the sustainable use and management of the Lamu Southern swamp mangrove ecosystem.

Executive Summary

Mangroves account for only 3% of Kenya's total forest cover, yet touted as one of the most productive systems with capacity to contribute significantly in climate change mitigation amongst other benefits. These ecosystems are known to be a biodiversity hotspot, being home, feeding and/or nursing grounds to unique birds, fish, mammals, plants, and microbial species and contribute significantly to the socio-cultural and economic wellbeing of the local community. However, the unprecedented degradation and loss of mangroves is causing a decline in biodiversity, leading to the potential local extinction of associated species and disrupting the intricate ecological balance of these unique ecosystems. In coming up with appropriate intervention measures, there is a need to understand both historical and current socio-ecological and political trends that influence selected actions. Moreover, finding a definitive connection between these components could be the key to successful management and conservation of these critical coastal ecosystems.

Kenya Marine Fisheries Research Institute (KMFRI) was tasked by Wetlands International to conduct a biodiversity and socio-economic assessment of the mangroves of Lamu Southern Swamp. The work which entailed analysis of both primary and secondary data, was done in collaboration with Kenya Forestry Research Institute, Kenya Forest Service, the University of Nairobi, CORDIO East Africa, and Nature Kenya. In addition to reviews of existing data and information, this report documents the findings of a survey conducted in the mangroves and adjacent villages in May 2024. The report outlines mangrove ecosystem dynamics focusing on linkages and drivers of degradation. It also delves on the legal and policy frameworks upon which biodiversity conservation and mangrove management is anchored. Socio cultural and economic trends of the local community are also documented. The report further provides an in-depth analysis of the Southern Swamp mangrove biodiversity including use of eDNA techniques. The study concludes in the last chapter by providing baseline scenarios relating to the climate and environmental conditions of the Lamu Southern swamp and concludes by developing restoration scenarios for evaluation of potential climate change mitigation benefits of mangrove restoration.

Table of Contents

Glossary

Biodiversity- A variety of life forms in diverse environments, encompassing species variety, genetic variability, and ecosystem complexity, which collectively maintain essential ecosystem functions like nutrient cycling, habitat formation, and resilience while also supporting human livelihoods through services such as fisheries, coastal protection, and climate regulation.

Climate Change- The significant variation of average weather conditions becoming, for instance, warmer, wetter, or drier-over several decades or longer.

Carbon Credit- A generic term for any tradable certificate or permit representing the right to emit one tonne of carbon dioxide or the mass of another greenhouse gas with a carbon dioxide (tCO_2e) equivalent to one tonne of carbon dioxide.

Carbon Stock- Quantity of organic carbon in a given pool(s) per unit area.

Climate Risk Assessment- A systematic process to identify potential hazards from climate-related events, trends, forecasts, and projections to develop plans to avoid/manage these risks.

Degradation- The deterioration or decline in the quality and health of forest ecosystems resulting from various human activities, natural processes, or a combination of both.

Driver: An agent of change in the ecosystem, either human-induced or a natural factor. Drivers can result in negative or positive effects on mangroves, so it's important to understand them for planning how to protect mangroves.

Ecosystem- A dynamic network of living organisms, such as plants, animals, and microorganisms, interacting with each other and their physical environment, like water, air, and minerals, with marine ecosystems specifically referring to ocean and coastal habitats where these interactions support biodiversity and life processes.

Ecosystem Boundaries - Natural or man-made limits within which ecological interactions and processes occur, such as the transition between mangrove forests and adjacent coral reefs, or seagrass influencing the distribution of species and flow of energy.

Endemic- The presence of a species exclusively within a specific geographical area.

Environmental DNA (eDNA) - The genetic material collected from environmental samples such as soil, water, air, or sediments, rather than directly from an organism.

IUCN Red List of Ecosystems- A global framework that monitors ecosystem status to aid conservation and resource management. It identifies ecosystems at high risk of biodiversity loss, working above the species level, and complements the IUCN Red List of Threatened Species. Its categories and criteria are designed to be broadly applicable, transparent, scientifically rigorous, and easily understandable by policymakers and the public.

Mitigation- Mitigation in the context of climate change refers to actions or activities that limit emissions of Greenhouse Gases (GHGs) from entering the atmosphere and/or reduce their levels in the atmosphere (IPCC).

Nature-based Solutions (NbS)- Projects that use natural landscapes to mitigate climate change, often while providing biodiversity co-benefits. Includes forestry, agriculture, and blue carbon projects.

Reforestation- Reforestation is the re-establishment of forest formations after a temporary condition with less than 10% canopy cover due to human-induced or natural perturbations (FAO).

Regeneration Classes- (RCI, RCII, or RCIII) Seedling categories based on height differences. RCI has heights less than 40 cm; RCII has heights between 41 cm and 150 cm, while RCII trees have heights greater than 1.5 m and less than 3 m but with a DBH< 2.5 cm.

Standard Precipitation and Evapotranspiration Index (SPEI)- is an index designed to take into consideration precipitation and potential evapotranspiration in determining drought.

Vulnerability- The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

List of Abbreviations and Acronyms

ACCNNR	African Convention on the Conservation of Nature and Natural Resources
ARA	Atmospheric Re-Analysis
BMU	Beach Management Unit
CBD	Convention on Biological Diversity
CFA	Community Forest Association
CHIRPs	Climate Hazards Center InfraRed Precipitation with Station Data
CIDP	County Integrated Development Plan
CMMC	County Mangrove Management Committee
CRU	Climate Research Data
DBH	Diameter at Breast Height
DO	Dissolved Oxygen
EAC	East African Community
eDNA	Environmental DNA
EMCA	Environmental Management and Co-ordination Act
EIA	Environmental Impact Assessment
EN	Endangered
ESA	European Space Agency
GBF	Global Biodiversity Framework
GBIF	Global Biodiversity Information Framework
GoK	Government of Kenya
HWM	High Water Mark
IGAs	Income Generating Activities
IUCN	International Union for Conservation of Nature
KEFRI	Kenya Forestry Research Institute
KFS	Kenya Forest Service
KMD	Kenya Meteorological Department
KMFRI	Kenya Marine and Fisheries Research Institute
KNBS	Kenya National Bureau of Statistics
KPHC	Kenya Population and Housing Census
LAMACOFA	Lamu Community Forest Association
LAPSSET	Lamu Port Southern Sudan-Ethiopia Transport

LC	Least Concern
MPA	Marine Protected Area
NBSAPs	National Biodiversity Strategy Action Plans
NCCRS	National Climate Change Response Strategy
NDCs	Nationally Determined Contributions
NE	Not Evaluated
NEMA	National Environment Management Authority
NEM	North-East Monsoon
NGAO	National Government Administration Officers
NMMC	National Mangrove Management Committee
NMEMP	National Mangrove Ecosystem Management Plan
NMK	National Museums of Kenya
NRT	Northern Rangelands Trust
NT	Near Threatened
PFMPs	Participatory Forest Management Plans
REDD	Reducing Emissions from Deforestation and Forest Degradation
SDGs	Sustainable Development Goals
SID	Society for International Development
SEM	Southeast Monsoon
SPEI	Standardised Precipitation Evaporation Indices
TDS	Total dissolved solids
TNC	The Nature Conservancy
UNFCCC	United Nations Framework Convention on Climate Change
VN	Vulnerable
WWF-Kenya	World Wide Fund for Nature Kenya

List of Figures

List of Tables

Chapter 1: Scope of the work

The purpose of this assignment was to assess the biodiversity and socio-economic issues in the Lamu Southern Swamp. The findings and recommendations would help in making informed decisions and developing holistic and integrated approaches towards the conservation and sustainable management of mangroves in Lamu, Kenya.

1.1 Specific Objectives

1. **Define ecosystems, their boundaries, functions and linkages** between different components of the ecosystem and highlight both **anthropogenic and natural drivers** contributing to the degradation of the mangrove ecosystems, as a basis for future interventions.
2. **Conduct a Review of Relevant Policy and Legislative Frameworks**: Review national and sub-national legislation, policies, and institutional frameworks related to mangrove conservation and biodiversity, and identify any gaps or needs for reform, paying particular attention to laws and regulations governing the implementation of mangrove conservation and management.
3. **Assess Socio-Economic and Cultural Factors**: Conduct a review of the socio-cultural, institutional, historical, and political contexts of the study area, including qualitative and quantitative assessments of local livelihoods, patterns of asset ownership, demographic changes, and development trends as well as external political or economic environment.
4. **Analyse Environmental Variables**: Investigate the environmental and physico-chemical parameters, including hydrology and ecosystem dynamics, to better understand the functioning of the ecosystem.
5. **Assess Biodiversity**: Evaluate the current biodiversity within the Lamu Southern Swamp, focusing on species composition, especially threatened and endemic species, as well as the ecological health of flora and fauna, with an emphasis on avifauna as key ecosystem health indicators.
6. **Develop Restoration and Climate Mitigation Scenarios**: Collaborate with Global Mangrove Watch and Kenya Forest Service to develop baseline and restoration

scenarios for evaluation of potential climate change mitigation benefits of mangrove restoration, making use of existing land use maps, carbon stock data per land-use class, topographic data and local sea level rise projections.

1.2 Study Site Description

This study was conducted in the Southern swamp mangrove block situated in between latitudes 1°45′ and 2°20′ South and longitudes 40°44′ and 41°30′ East of Lamu County, Kenya. According to the GoK (2017), Lamu County features a 130 km coastline with mangrove forests covering approximately 37,350 ha out of Kenya's total estimated mangrove coverage of 61,271 ha, representing 61% of the country's mangrove cover. The mangroves are found around creeks in Lamu mainland and 65 islands forming the Lamu archipelago. The Lamu mangroves consist of unique indigenous forest woodlands with nine mangrove species. For effective management, the Kenya Forest Service (KFS) subdivided the mangroves of Lamu County into five management blocks, namely the Northern swamp, Northern Central swamp, Mongoni and Dodori Creek swamp, Pate Island swamp, and Southern swamp.

The Southern swamp is the largest block and encompasses Mkunumbi, Shella, Amu Island, Kimbo Creek, Manda Island, Kililana, Mokowe, and Matondoni. This block hosts 5200 ha of mangroves, representing 14% of the county's total mangrove cover (GoK, 2017). The area has a bi-modal rainfall pattern which is heavily influenced by the South East Monsoon (SEM) and North East Monsoon (NEM) winds. Short rains occur between March and May (SEM) while long rains occur during October to December (NEM) period. Relative humidity in the region is constantly high, surpassing 90% during the rainy season (GoK, 2017). The Lamu mangrove Participatory Forest Management Plan (PFMP) 2022-2026 describes the area as flat and low-gradient, thus prone to flooding during the rainy season and periods of high tides. The Southern swamp comprises three distinct landscapes including the seascape, the immediate coastal plain landscape, and the gentle rising landscape unit (Lamu CIDP, 2023).

Thanks to its rich biodiversity and unique marine and terrestrial ecosystems, the Southern Swamp mangroves support various economic activities including fishing, beekeeping and honey harvesting, eco-tourism, seaweed farming, tree nursery establishment and cattle rearing thus promoting the local economy and subsequently improving livelihoods. The Southern swamp is divided into two sub-blocks, managed by two Community Forest

Associations (CFAs), that is, Lamu CFA and Mkunumbi CFA (Lamu mangrove Participatory Forest Management Plan 2022-2026).

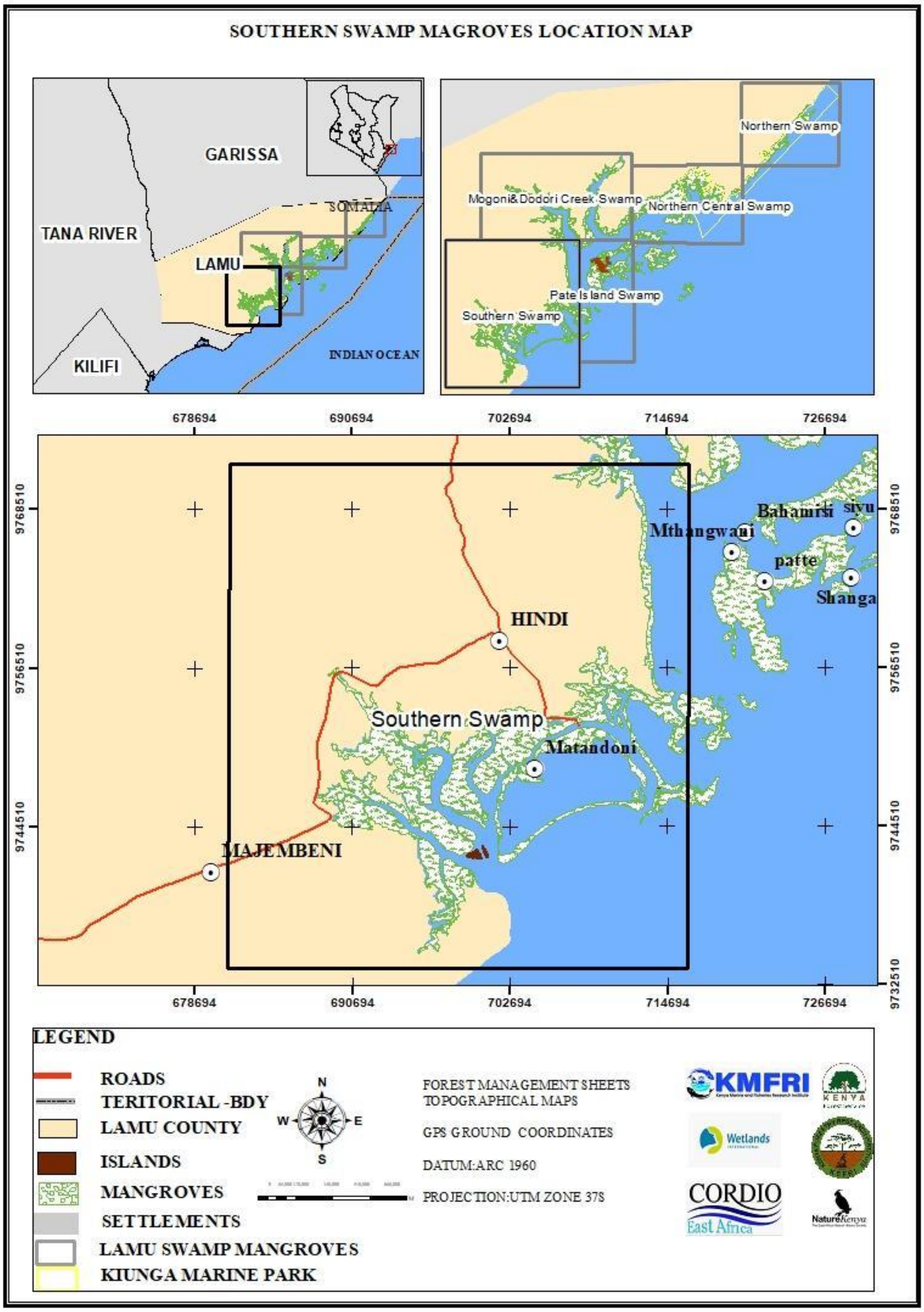

Figure 1: Map of the mangroves of the Southern Swamp. Inset is map of Kenya situating the Lamu mangroves and the 5 management blocks

Chapter 2: Understanding Ecosystem Dynamics and Drivers of Mangrove Degradation

The term mangrove could be applied to infer a tree, forest, or an ecosystem which exists within the intertidal areas of the tropical and subtropical coastlines between the mean low and highest water mark (Miththapala, 2008; Spalding, 2010; Friess *et al.*, 2019). In Kenya, there are nine mangrove tree species with *Rhizophora mucronata* and *Ceriops tagal* being the most common species constituting about 70% of the entire mangrove formations (GoK, 2017). Mangrove forests are composed of diverse tree species that form a distinct community of woody plants. These woody plants together with associated biotic and abiotic factors constitute the mangrove ecosystem.

2.1 Ecosystem Boundaries

Ecosystem boundaries refer to the zones or edges that separate one ecosystem from another (Banks-Leite & Ewers, 2009). These boundaries can be physical, biological, or conceptual, and often mark the transition between different environments, habitats, or ecological communities (Strayer *et al.*, 2003). In addition, ecosystems demonstrate both spatial and temporal boundaries that highlight the area where diverse communities relate to their physical environment and create sophisticated energy movement and nutrient balance interactions. They are key players in regulating species movement, nutrient flow, and energy exchange. Ecosystem boundaries can vary in clarity, origin and maintenance, spatial structure, function, and temporal dynamics depending on the nature of the ecosystems involved (Strayer *et al.*, 2003). Post *et al.* (2007) demonstrated that these borderlines allow scientists and ecologists to determine regions where specific ecological events unfold.

Mangrove ecosystem boundaries can be natural such as rivers, creeks or bays among other coastal relief features or manmade such as cities or infrastructure defined through time and space (Rog & Cook, 2017). These boundaries are dynamic, influenced by both natural processes and human activities, resulting in shifting and evolving zones. The mangroves in Kenya are geomorphically bound by the coastal plains, which are the lowest in altitude and reach a maximum elevation of 140 metres above sea level (GoK, 2017). On a local scale, mangrove ecosystem boundaries are primarily and naturally influenced by tidal movements, salinity gradients, and sediment deposition, all of which contribute to their dynamic nature

(Ellison, 2021). In areas where such natural processes dominate, mangrove boundaries tend to be permeable, facilitating the exchange of resources such as nutrients, sediments, and organisms with adjacent ecosystems like coral reefs and seagrass beds (Strayer *et al.,* 2003). This permeability enhances ecological connectivity, enabling resource sharing and supporting the health and biodiversity of neighbouring habitats (Strayer *et al.,* 2003; Bosire *et al.*, 2014).

2.2 Ecosystem Linkages and Functions

Ecosystem linkages can be classified as intrinsic, which entails interconnectedness amongst the communities within the ecosystem or extrinsic which demonstrates how one ecosystem is linked to another beyond defined boundaries for the purpose of interaction and connection. Such links enable flow of energy within and without the ecosystem which drives primary productivity (Minu *et al.,* 2020).

2.2.1 Intrinsic Ecosystem Linkages

The complexity and heterogeneity of the mangrove vegetation structure and diversity maintain ecosystem functions and facilitate colonisation of diverse faunal communities (Ferreira *et al.*, 2015). The faunal community in turn influences the mangrove structure and functioning through burrowing and grazing, particularly the macrobenthic species that thrive within mangroves (Ellison, 2008). Additionally, mangroves form an essential link between mangrove detritus and consumers at higher trophic levels and are thus often used as bioindicators of a thriving ecosystem (Cuenca *et al.,* 2015). Such efficient food web systems in the mangrove ecosystem plays a significant role in regulating the ecological populations and processes within the ecosystem which ensures species balance and ecosystem stability (Friess *et al.,* 2020).

Studies by Panda *et al.* (2019) and Akter *et al.* (2020) focused on a unique link between high biodiversity in the mangroves and pollinators. The pollinators including some canopy-dwelling species like bees, bats, moths, and birds facilitate sexual reproduction in angiosperms such as mangroves, making them crucial for biodiversity and ecosystem integrity preservation. In return, the mangroves provide habitat and resources such as nectar for the pollinators thus fostering mutual benefits between each other. Moreover, the pollination ecology was found to affect the forest structure and the behaviour of animals in the mangroves, offering insights into the plant community's organisation and the adaptation of visitors in response to the flower pollination process (Chakraborti *et al.,* 2019).

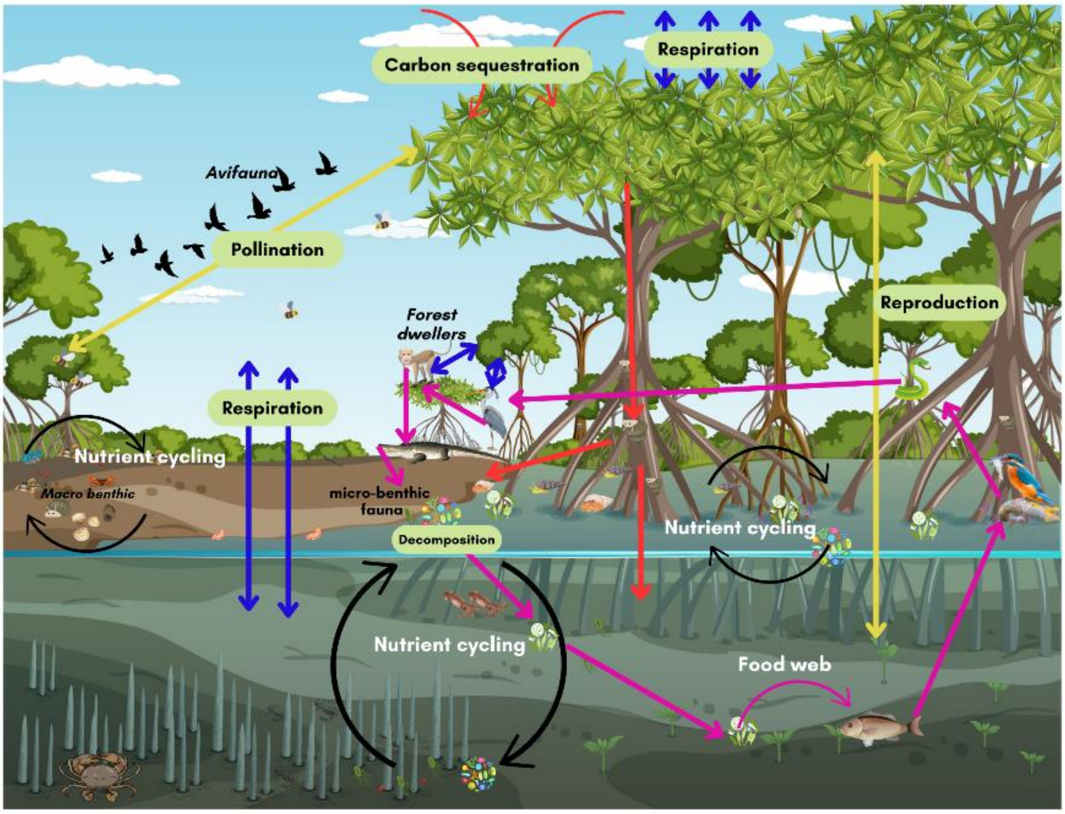

Figure 2: Intrinsic linkages within the mangrove ecosystem

2.2.2 Mangrove Ecosystem Connectivity

Other than the intrinsic linkages, studies have demonstrated connectivity among mangroves, other estuarine ecosystems (river drainage basins), seagrass beds and the coral reef (Onrizal*et al.,* 2020; Arceo-Carranza *et al.,* 2021; Bastos *et al.,* 2022). The mangrove ecosystem is strategically positioned to ecologically support these ecosystems since it occupies. These ecosystems occupy the dynamic land-sea transition zone, which enables beneficial reactions to take place between them (Carlson *et al.,* 2021). The unique interconnectedness amongst these four ecosystems take part in biogeochemical and trophic exchange activities enabled by migratory coastal organisms (Bouillon & Connolly, 2009; Arceo-Carranza *et al.*, 2021; Triest *et al.*, 2021; Bastos *et al.*, 2022). Mangroves play a crucial role in maintaining nutrient budget dynamics, which regulate and support ecosystem processes that extend beyond their boundaries into adjacent marine environments. As highlighted by Minu *et al.* (2020), mangroves facilitate nutrient cycling, particularly for key elements such as carbon, nitrogen, and phosphorus, thereby sustaining broader ecological functions across connected ecosystems.

A variety of marine species utilise the mangrove ecosystem ontogenetically, shifting among estuarine river drainage basins, between seagrass and coral reefs thus tethering them through their movement (Granek, 2006; Kimirei*et al.*, 2013; Bastos *et al.*, 2022). Mangroves, estuarine river drainage basins and seagrass beds act as key nursery areas, providing habitat for a variety of juvenile species before they migrate to their adult stage habitats (Saenger *et al.*, 2013; Arceo-Carranza *et al.*, 2021; Hernandez, 2021). Granek (2006) highlighted the intricate ecological interconnectedness between mangrove and coral reef ecosystems, using the example of the Mangrove Red Snapper (*Lutjanus argentimaculatus*). This species spawns in coral reefs but relies on mangrove habitats for sustenance, primarily feeding on Sesarmid crabs, which inhabit mangroves and consume detrital leaves from these trees. Furthermore, mangroves serve as critical habitats for endangered marine species, including green turtles, hawksbill turtles (Wedemeyer-Strombel *et al.,* 2021), dugongs (Keith-Diagne *et al.,* 2022), scalloped hammerhead sharks (Rangel-Morales *et al.,* 2022), and Goliath groupers (Condini *et al.,* 2024). By providing refuge and essential resources, mangroves play an indispensable role in safeguarding these species from the threat of extinction.

Bosire *et al.* (2012) further supports the benefits accruing from the ecological interconnectedness amongst critical marine habitats by noting that a number of coral reef-inhabiting species are believed to be either facultative or obligate utilisers of the mangrove habitat at certain life stages. Furthermore, the study illustrates the unique role of mangrove ecosystems in regulating the sediment budget that protects the coral reef and the seagrass ecosystems. Various reef species including reef fish utilise the mangrove ecosystem and seagrass beds for feeding, breeding, or both. These activities facilitate the transfer of allochthonous nutrients into the coral reef ecosystem, enriching it with mangrove-derived nutrients (Granek, 2006; Whitfield, 2017). Studies suggest that coral reefs adjacent to the mangroves host diverse economically important species compared to those far from mangroves, reinforcing the mangrove nursery habitat theory (Granek, 2006). Apart from coral reef species, other marine organisms utilise the mangroves as shelter during the day and use either seagrass, river ocean drainage basins (estuaries and deltas), mangroves, or a combination of all as foraging grounds at night (Nagelkerken *et al.,* 2000). Several species use the ecosystems simultaneously, shifting between them to feed or cope up with changing seasons. The intricate feeding and breeding dynamics among mangrove, coral, and seagrass ecosystems play a significant role in shaping their community structures (Bosire *et al.,* 2012; Granek, 2006). Positioned at the interface of land and sea, mangroves form a vital link between terrestrial and marine ecosystems (Palit *et al.,* 2022). By regulating sediment flow from land, mangroves and seagrasses help prevent excessive sedimentation, which can smother coral reefs and lead to coral mortality (Waycott *et al.,* 2011; Bosire *et al.,* 2012). Conversely, coral reefs and seagrass meadows offer protection to mangroves by buffering strong wave action and promoting essential biotic exchanges within the mangrove ecosystems (Saenger *et al.,* 2013; Girkar *et al.,* 2024).

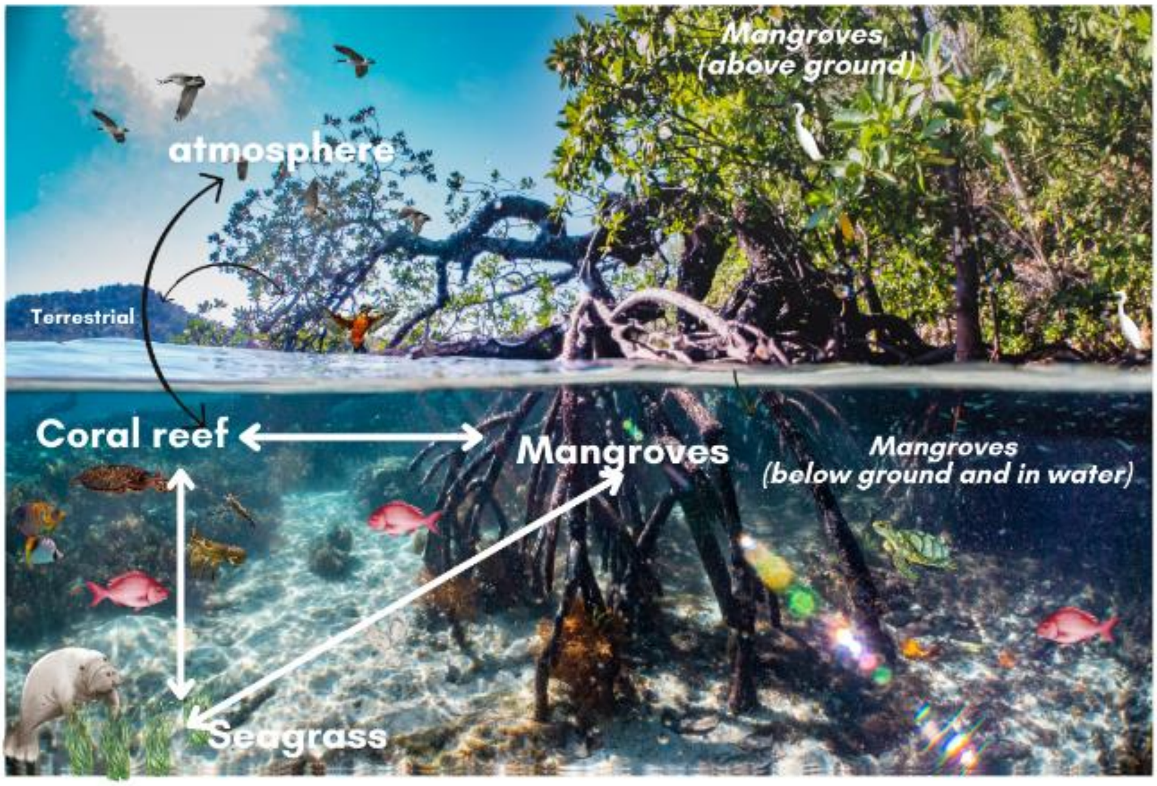

Figure 3: Extrinsic linkages of mangrove ecosystem with other ecosystems

Together, estuarine river basins, mangroves, seagrass, and corals form a carbon-rich ecosystem (Cunha-Lignon *et al.,* 2022). The mangrove ecosystem produces organic carbon that is either stored in local soils or transported by tides to adjoining coastal waters in the form of detritus (Torgersen & Chivas, 1985). Studies have shown that much of the organic carbon found in seagrass meadows surrounded by mangroves originate from the mangrove ecosystem. Seagrass subsequently transfers mangrove derived organic and inorganic carbon towards the open ocean (Chen *et al.,* 2017).

Highlighting the critical importance of marine ecosystem linkages, Alongi (2021) identifies mangroves as essential ecological networks that perform key functions across both spatial and temporal scales. These functions extend beyond maintaining environmental health, encompassing biodiversity conservation and climate resilience, directly benefiting both human and ecological well-being (Alongi, 2020; Segaran *et al.,* 2023). Mangrove ecosystems support a rich faunal diversity, hosting terrestrial and marine, migratory and resident, as well as macro and microscopic species (Macintosh *et al.,* 2002). Furthermore, mangroves play a pivotal role in regulating biogeochemical processes through bioremediation, helping to detoxify pollutants and maintaining essential ecological connections with neighbouring ecosystems, such as coral reefs and seagrass beds (Sundaramanickam & Balasubramanian, 2021). As transitional habitats between land and sea, mangroves provide crucial shoreline protection, support carbon sequestration, contribute to climate regulation, and offer defence against coastal erosion and storm surges (Lee *et al.,* 2014).

2.2.3 Human-Mangrove Interactions: A Socio-Ecological Perspective

While it is an ecotone of biodiversity, mangrove ecosystems are at the pinnacle of direct impact on the livelihood of coastal communities (Ragavan *et al.,* 2021). Mangroves have for a long time been harnessed by the local communities for ecosystem goods including wood and poles for boat and house construction, charcoal, dyes, tannins, and firewood (Abuodha & Kairo, 2001). Use of mangrove wood products particularly for construction and fuelwood are ranked highest among benefits accrued from mangrove forests by the local communities in Lamu. The mangroves are additionally utilised by the local communities for medicinal purposes, honey and wax collection, and harvesting of mollusc and shells (Das *et al.,* 2022; Riungu*et al.,* 2022). Mangroves also serve as fishing grounds for the local community particularly crabs, and some fish species found along the creeks and channels, hence an essential source of food and income for the local communities (Das *et al.,* 2022). With the advent of sustainable mariculture along the coast of Kenya, local communities are venturing into fish farming within the bare tidal flats of the mangroves and cage culture in the creeks. Further, owing to their situation in the interface between land and sea, mangroves offer coastal protection and shoreline stabilisation, flood control, and storm protection, (Mitra & Mitra, 2020) all of which are vital for safeguarding property and life.

2.3 Southern Swamp Status and Degradation Trends

Mangroves of Kenya extend along the country's 574 km coastline, covering approximately 61,000 hectares, which constitutes 3% of Kenya's total natural forests and 1% of the country's total land area (GoK, 2017). These mangroves are primarily found in creeks, sheltered bays, estuaries, and lagoons (Kirui, 2013; Bosire *et al.*, 2016)). Notably, Lamu County accounts for over 60% of Kenya's mangrove cover, with its mangrove ecosystems recognized as some of the most productive in the region (Kairo *et al.*, 2002; GoK, 2017).

2.3.1 Degradation trends

Despite mangroves supporting a significant amount of global biodiversity and providing a wide range of ecosystem services that contribute to the well-being of coastal residents, the depletion of these resources or changes in management policy poses significant threats to resource-dependent communities both socially and economically (Bosire *et al.*, 2014). The sustainability and effectiveness of mangrove management depend largely on the socioeconomic conditions of the local mangrove-depended communities (Kairo *et al.*, 2001). Despite the awareness of the importance of marine natural resources, particularly mangroves, their exploitation is still alarming due to economic dependency and lack of alternative sources of energy for their daily use (Bosire et al., 2016)), inflicting substantial pressure on the mangrove forest.

The mangrove forests in Kenya have faced significant degradation with an approximate net annual loss of 0.15% (Hamza *et al.*, 2022) with the mangroves of Pate-Kiunga in Lamu recording an annual loss of 1.19% albeit some gain in cover (Okello *et al.*, 2022). This rate of mangrove loss is slower compared to the 0.7% per year recorded between 1985 and 2010 (Kirui *et al.*, 2013). Additionally, Bosire *et al.* (2014) revealed that anthropogenic pressure has contributed to the loss of up to 1-2% per annum of peri-urban mangroves in Kenya, with the focus in Mombasa for the last half a century. In Lamu, anthropogenic activities (Kairo *et al.*, 2021; Okello *et al.*, 2022; Mbatha *et al.*, 2023) and natural mortality (Okello *et al.*, 2022) have mainly contributed to a loss of at least 1,739 ha (4.87 %) of mangroves between 1990 and 2019 representing a decline of 60 ha yr^{-1}. Inventories conducted in 1967 and 1982 revealed escalating deforestation of mangroves in the Southern swamps and over-exploitation of two principal species i.e. *R. mucronata* and *C. tagal* significantly depleting their growing stocks (GoK, 2017). Clear felling for fuelwood used in traditional lime making was carried out in vast parts of Manda Island and other parts of the southern swamps. In addition, it has been demonstrated that during the 1997/98 El Nino, parts of the southern swamp were impacted by flooding and the mangroves have not recovered fully because of poor natural regeneration (GoK, 2017).

2.3.2 Prevailing Drivers of Mangrove Degradation and Loss

Drivers of mangrove degradation and loss refer to the various factors, processes, or activities that lead to the deterioration or destruction of mangrove ecosystems. These drivers can be natural or human-induced resulting in the loss of biodiversity, disruption of ecosystem services and the diminishing capacity of mangroves to provide ecosystem services (Polidoro *et al.*, 2010). Essentially, they are the underlying causes contributing to the weakening or elimination of mangrove ecosystems.

Poverty

According to the Kenya Poverty Report (2021), Lamu County has a poverty headcount rate of 35.1%, reflecting significant economic challenges. Due to the low-income levels, residents resort to unsustainable practices like cutting down mangroves for sale as an alternative income source. Moreover, according to the survey report conducted by the Kenya National Bureau of Statistics (KNBS) and the Society for International Development Survey (SID) in Lamu County in 2019, over 93.7% of residents were relying on wood and its derivatives for fuel. This creates overdependence and pressure on the mangrove forests, leading to overharvesting for their daily subsistence.

Population Pressure

In Lamu, at least 1,739 ha of mangroves were lost between 1990 and 2019 mainly due to anthropogenic activities, representing a decline of 60 ha yr-1 (Kairo *et al.*, 2021). Lamu had a population of 143,920 in 2019 and by 2023, it was projected to have grown to 167,332, representing an approximate annual growth rate of 4% (KNBS, 2019). An increase in population has been found to result in an increase in the demand for natural resources including mangroves. This often leads to the overexploitation of mangrove forests for building poles, timber, firewood and charcoal for daily subsistence and commercial purposes to meet the high demands (Riungu *et al.*, 2023). Additionally, Akram *et al.* (2023) demonstrated that population growth leads to high pollution from waste and sewage, which damages mangrove habitats. Moreover, the upcoming Lamu port in the Southern block is expected to increase the human migration into the area, which is expected to increase pressure on the forest.

Wood Source Preference and Limited Alternatives

Due to the easy accessibility of mangrove trees for fuel and wood products, most Lamu residents prefer the use of mangrove wood for daily use and commercial purposes. Boriti and Mazio are mostly preferred for construction due to their durability (Riungu *et al.,* 2023). Rhizophora species is often preferred for fuelwood and charcoal because it produces little smoke, burns for a long time, and its wood has high calorific value (Gallup *et al.,* 2020). For commercial purposes, the high market value of Boriti and Mazio wood leads to frequent overharvesting of mangrove trees by residents to maintain a steady supply (Riungu *et al.,* 2023). Similarly, the lack of alternative sources of wood and wood products drives mangrove degradation as local communities heavily depend on mangrove forests for timber, firewood, and construction materials (Nyangoko *et al.,* 2022). Without access to affordable or sustainable alternatives, people overharvest mangroves to meet their daily needs for fuel and building materials.

Inadequate Awareness

Inadequate awareness can be defined as lack of understanding or knowledge among local communities, policymakers, and other stakeholders about the ecological importance, sustainable use and management of mangrove forests. Ahmed *et al.* (2023) and Chisika & Yeom (2023) revealed that the awareness gap in Lamu County has led to the undervaluation of mangrove benefits and misguided restoration efforts and management of mangroves. When communities or decision-makers are unaware of the environmental and economic value of mangroves, they may prioritise short-term activities like logging, land reclamation, or aquaculture over conservation. This can cause unsustainable exploitation, habitat destruction, and ultimate degradation and loss of mangrove forests.

Inappropriate Farming Practices

Runoff from agricultural farms containing fertilisers and pesticides pollutes coastal waters, harming the ecosystem. Poor land use practices in the hinterland have increased sediment loads in the mangroves, leading to the siltation that suffocates breathing roots of the trees and the eventual death of the system (Wekesa *et al.,* 2023). Furthermore, Poor soil management causes sedimentation and erosion that smothers mangrove roots, thus inhibiting their growth.

Mangroves also stabilise coastal soils, but agricultural encroachment weakens this, increasing erosion and vulnerability to flooding. By reducing mangrove buffer zones, farms expose both ecosystems and agricultural land to environmental damage.

Weak Governance Structures

Weak governance and enforcement of laws has contributed significantly to the degradation of mangroves in Lamu County, allowing illegal logging and overharvesting to thrive. Insufficient resources have limited the ability of local authorities to monitor and control illegal activities effectively. While the Kenya Forest Service (KFS) also controls mangrove harvesting through the issuance of licences, these permits are often granted based on wood demand rather than the actual availability of resources (Riungu *et al.,* 2023). Additionally, the lengthy process of obtaining licences sometimes drives communities to resort to illegal harvesting of mangroves (Dahdouh-Guebas *et al.,* 2000). Moreover, Chisika and Yeom (2023) demonstrate that the lack of adequate government and stakeholder involvement in mangrove protection and management also contributes to illegal logging and cutting. This lack of governance and accountability accelerates the loss of mangrove ecosystems.

Conflicting policies further exacerbate the degradation of mangroves by creating confusion, inefficiency, and uncoordinated management. Kairu *et al.* (2024) revealed that the shift from centralized to decentralized policies governing mangrove ecosystems in Lamu County has led to conflicts. The lack of integrated policies and the persistence of siloed approaches among various government agencies, such as forestry, fisheries, and coastal development, have caused significant overlaps. These conflicting policies hinder the effective enforcement of mangrove protection laws, leading to illegal logging, unsustainable resource harvesting, and attempts to restore mangrove trees in unsuitable environments.

Cultural Erosion

Cultural erosion refers to the gradual loss or weakening of a community's cultural identity, traditions, customs, values, and practices due to external influences or internal changes. From time in memorial, the Swahili culture has been linked directly to the ocean. However, in the recent past, the Swahili people are pursuing other occupations primarily in terrestrial-based agriculture, and cottage industries. These occupations include sandal making; brass working; wood carving; jewellery making; making of embroidered caps and clothing; mat/bag weaving; manufacture of iron tools and weapons, and other trades. From all these occupations they became wealthy people. However, it is their maritime activities that gave the Swahili their prosperity. This maritime trade had greater consequences than just an improvement of the local economy as it created a whole new civilisation. (Idha, 1998) reported that the direct connection between the Swahili people and ocean had enabled them to embrace practices that protected the mangrove forests which form part of the ocean. However, the arrival of the Portuguese in the 16th century undermined local governance and resource management, breaking down sustainable practices that protected mangroves. As a result, the decline of Swahili maritime culture, along with modern economic pressures, has led to unsustainable harvesting and loss of cultural knowledge. This erosion of traditional practices has left Lamu's mangroves vulnerable, highlighting the urgent need to revive cultural practices that once safeguarded these vital ecosystems to prevent further environmental degradation.

Economic Development

The National Spatial Plan under The County Integrated Plan (2023-2027) projects Lamu County to have rapid economic growth due to its locational advantages and as an alternative growth area because it hosts the Lamu Seaport and the Lamu Port-South Sudan-Ethiopia Transport (LAPSSET) project (Kamau & Maritim, 2024). Economic development in Lamu, particularly through infrastructure projects like the LAPSSET Corridor and the seaport, has contributed to mangrove degradation and loss through clearing of mangroves to cater for development (NEMA, 2013). The Kenyan government is keen to expand its bilateral trade and add more trade routes towards the Northern neighbouring countries under the LAPSSET project (Lesutis, 2020). At the crossroads with these ongoing development projects is the Southern mangrove block where the inhabitants may experience significant changes that will most likely interfere with their livelihood (Rodden, 2014), and possibly decimate the biodiversity of the stated mangrove block (Omenge *et al.*, 2022). How these projects will shape the blocks' hydrodynamics, biodiversity patterns, and socio-economic activities of the local communities remains a conjecture, as there is no relevant study to ascertain the overall impact.

Climate Change

Extreme climate change events such as unprecedented flooding due to El Nino, storms, cyclones, sea-level rise, and coastal erosion have been found to cause mangrove degradation locally, regionally and globally (Njenga *et al.* 2024; Bhowmik *et al.*, 2022; Hamza *et al.*, 2022). Mangroves are extremely sensitive to changes in salinity, flood duration, frequency and magnitude which affects their growth and survival. However, studies have shown that mangroves can adapt to sea-level change by moving upslope or increasing elevation through sedimentation so that they remain within the same tidal range. During the El Niño (1997-1998), widespread die-backs of mangroves were observed in Lamu and Mida Creek due to massive sedimentation and prolonged submergence of mangroves in stagnating water (Wekesa *et al.,* 2023, Mangora *et al.,* 2014).

Chapter 3: Existing Policies and Legislations on Biodiversity and Mangrove Conservation

Legal frameworks and policies for biodiversity conservation are essential in ensuring the sustainable use and management of resources. These frameworks have been put in place to provide structured regulations to safeguard ecosystems against anthropogenic drivers of degradation as well as emerging threats related to climate change. These policies help mitigate the impacts of climate change, habitat loss, pollution and overexploitation by setting clear conservation goals and promoting sustainable practices. They also foster international cooperation, ensuring that countries work together to conserve biodiversity across borders.

3.1 International Policies and Institutional Frameworks on Biodiversity

The **Convention on Biological Diversity (CBD)** stipulates that member states must conserve their biological diversity, use their biological resources sustainably and have the fair and equitable sharing of the benefits arising from utilising genetic resources. It was established to address the growing global concern over the rapid loss of biodiversity and its impact on ecosystems, human livelihoods, and sustainable development. To further address the challenges of the global loss of biodiversity, the Conference of Parties (COP) to the UN Convention on Biological Diversity saw the adoption of the **Kunming-Montreal Global Biodiversity Framework (GBF)** during COP 15 in 2022. These frameworks were implemented to replace the **Aichi Biodiversity Targets** established in 2010 as part of the Strategic Plan for Biodiversity (2011-2020).

The Kunming-Montreal GBF goal is to halt and reverse biodiversity loss by 2030 and set a pathway to reach the global vision of living in harmony with nature by 2050. The key goals include protecting 30% of the world’s land and marine areas, restoring 30% of degraded ecosystems, and reducing species extinction rates. This agreement emphasises the sustainable use of natural resources, reduction of pollution, and financial support for biodiversity-rich developing nations.

The Convention on Biological Diversity (CBD) and Global Biodiversity Framework (GBF) strongly support the **United Nations Sustainable Development Goals (SDGs).** The

Kunming-Montreal GBF aligns closely with SDGs, especially those related to environmental sustainability, climate action, and poverty reduction. They include SDG 1 on No Poverty, SDG 2 on Zero Hunger, SDG 15 on Life on Land, SDG 14 on Life Below Water, and SDG 13 on Climate Action. Additionally, the United Nations General Assembly in March 2019 implemented the **United Nations Decade on Ecosystem Restoration 2021–2030**, which supports the achievements of the SDGs regarding restoration of ecosystems, enhance biodiversity, mitigate climate change, and improve human well-being. The decade is set to coincide with critical global timelines, such as the deadline for the Sustainable Development Goals.

As a member state of the Conference of Parties to the **Convention on Biological Diversity,** Kenya has adopted and developed National Biodiversity Strategy Action Plans (NBSAPs) that contribute to the frameworks and policies of **CBDs Aichi Target 15",** which focuses on carbon stock enhancement, biodiversity conservation and ecosystem resilience. This promotes the restoration of degraded mangrove habitats and biodiversity conservation. Furthermore, Kenya is expected to update its **National Biodiversity Strategy and Adaptation Plans 23 (NBSAPs)** to align with the **Global Biodiversity Frameworks (GBF)** goals by COP 16 in 2024, which provides an opportunity for governments to incorporate mangrove action into their new plans.

The "Gazette Notification for Mangrove Forests in Kenya" describes the mangrove ecosystem **as all land between high and low watermarks**. Additionally, the **Convention on Wetlands of International Importance (Ramsar Convention)**, 1971, classifies the mangrove ecosystems as 'wetlands' due to the flooding or saturation of water either seasonally or permanently. The convention provides frameworks for international and national cooperation for the wise use of the wetlands and their resources. The Tana River Delta has been designated as the 6th Ramsar site in Kenya due to its unique and diverse range of coastal wetlands, including mangroves.

The **Global Forest Goals and Targets 2019** are voluntary targets that support the sustainable management of forests and align with international frameworks on forest management, such as the **Paris Agreement, Sustainable Development Goals,** and the **United Nations Framework Convention on Climate Change (UNFCCC)**. In 2005, a set of policies known as "Reducing emissions from avoided deforestation and forest degradation or REDD+ was introduced during COP11 of the **(UNFCCC)** to reduce emissions and enhance carbon stocks through actions that address deforestation, forest degradation, forest conservation and sustainable forest management.

Furthermore, the **National Climate Change Response Strategy (NCCRS) has also provided the framework** for re-orienting national programmes towards a low-carbon development pathway. The strategy aims to achieve climate-proof socioeconomic development anchored on a low-carbon path. As of 2023, 97 countries have included coastal and marine ecosystems, including mangroves, in their **Nationally Determined Contributions (NDCs) to the Paris Agreement,** and 61 countries have included conservation or restoration of blue carbon ecosystems as a mitigation and/or adaptation measure. Many of these specifically call out mangroves.

3.2 Regional Policies and Institutional Frameworks on Biodiversity

3.2.1 East Africa Community Treaty, 2000

The treaty emphasises the importance of cooperation management and sustainable utilisation of natural resources for mutual benefit. Chapter 19, Article 111 supports developing and implementing programs, strategies, policies, and legislation to attain sustainable conservation and management of these forests. Article 114, section 2(a)(i) concerning the conservation and management of forests by taking necessary measures through the adoption of common policies and exchange of information on the conservation and management of natural forests.
Thus, these joint efforts by nations make it easy to manage transboundary resources, especially those from which mangroves form. By jointly promoting common forestry practices within the East African communities, joint utilisation of forestry training and research facilities establishes uniform regulations for managing forestry resources.

3.2.2 African Convention on the Conservation of Nature and Natural Resources (ACCNNR) - 1969

The provisions of the Convention are contained in the Agricultural Act regarding soil conservation measures. This convention supports the importance of conserving natural resources in the mangrove forest, and the land on which the resources are situated must be restricted. Therefore, in accordance with this Convention, tracks of land naturally occupied by flora and fauna should be reserved to protect this element of nature.

3.2.3 African Union Biodiversity Strategy and Action Plan (ABSAP 2023-2030)

Twenty-three intervention areas have been defined as critical in triggering the required shift across the Strategy's different pillars. These interventions are aligned with the Global Biodiversity Framework (GBF) targets, as well as targets from other biodiversity-related Multilateral Environmental Agreements (MEAs). This Strategy recognises the need for a multiscale intervention approach and thus provides, firstly, for priority actions adapted to national realities and the development needs of AU Member States. Secondly, regional and continental mechanisms are defined to strengthen collaboration and cooperation in transboundary shared ecosystems, and in support of efforts by Member States.

3.2.4 The Nairobi Convention

The Convention entered into force in 1996 with a vision of a prosperous Western Indian Ocean (WIO) region with healthy rivers, coasts and oceans. To realise the vision, the Convention aimed at increasing the capacity of the Western Indian Ocean nations to protect, manage, and develop their coastal and marine environment. The Nairobi Convention aims to address the accelerating degradation of the world's oceans and coastal areas through the sustainable management and use of the marine and coastal environment. It does this by engaging countries that share the Western Indian Ocean in actions to protect their shared marine environment.

3.3 National policies and institutional frameworks on mangrove conservation and biodiversity

Kenya's national legislation and policies governing mangroves aim to protect and sustainably manage these vital coastal ecosystems.

3.3.1 The Constitution of Kenya, 2010

Under the Constitution of Kenya 2010, Article 42 states that every citizen has a right to a clean and healthy environment. The Kenyan government aims to ensure sustainable environmental management and conservation that provides for sound conservation and protection of ecologically vulnerable areas as per Article 60(1) and provides for concerns linked to the environment as per Article 69(1). Kenya has enacted national legislation and policies to translate these constitutional mandates into actionable measures. National legislations and policies have been put in place to attain and maintain a 10% tree cover, protect biodiversity and Indigenous knowledge, encourage public participation, protect genetic resources, establish environmental impact assessment systems, eliminate endangerment processes, and use resources for the benefit of Kenyans, ensuring equitable sharing of benefits.

3.3.2 Forest Policy (2014), Forest Conservation and Management Act (2016) & Kenya Forest Service (KFS) Strategic Plan (2023/2027)

Mangroves were declared government reserve forests by Proclamation No. 44 of 30th April 1932 and later by Legal Notice No. 174 of 20th May 1964. Under the "Gazette Notification for Mangrove Forests in Kenya", mangrove areas are classified as the land between high water and low water marks (ordinary spring tides). The declaration bestowed the conservation and management of the mangrove ecosystem under the Forest Department. Later, the Kenya Forest Service was established under the Forest Conservation and Management Act No. 34 of 2016. However, where mangroves occur in the Marine Protected Areas (MPA), they are managed in partnership with Kenya Wildlife Service (Chisika & Yeom, 2023)

3.3.3 Environmental Management and Coordination Act, 1999 (Amended in 2015)

This is an Act of Parliament establishing a legal and institutional framework for the management of the environment. Section 42 (2) of the Act empowers the Minister responsible for environment to declare a lake shore, wetland, coastal zone or river bank to be a protected area and to impose such restrictions as he considers necessary to protect the same. Section 42 (3) of the Act further empowers the Minister to issue general and specific orders, regulations or standards for the management of river banks, lake shores, wetlands or coastal zones. In addition to the foregoing, Section 55 (1) empowers the Minister to declare an area to be a protected coastal zone while Section 55(2) and (3) mandates NEMA to prepare a survey of the coastal zone and thereafter develop an integrated national coastal zone management plan every two years based on the survey report. Section 55 (4) requires that the Management Plan shall, amongst other things, include an inventory of the state of the coral reefs, mangroves and marshes found within the coastal zone, an inventory of all areas within the coastal zone of scenic value or of value for recreational and cultural purposes, an estimate of the extent, nature, cause and sources of coastal pollution and degradation, an estimate of fresh water resources available in the coastal zone and inventory of all structures, roads, excavations, harbours, outfalls, dumping sites and other works located in the coastal zone.

3.3.4 The Physical Planning Act of 1996 and the Physical and Land Use Planning Act of 2019

This legislation provides for or the planning, use, regulation and development of land and for connected purposes. Sections 4 and 5 of this Act proclaims that development should be in harmony with environmental considerations, and the Director of Physical Planning has powers to declare special planning areas that could conceivably apply, inter alia, to the unique coastal ecosystems on land areas owned by government, held in trust by Count Governments or private within the area of the authority of a city, municipal, town, or urban council or with reference to any trading or market centre. However, given the sectoral approach to planning, abuse of influence and inadequately regulated development along the coast, physical development has often not mainstreamed environmental concerns, resulting in degradation of environmentally sensitive areas, loss of beach access points, beach encroachment and shoreline erosion.

3.3.5 The Land Act, 2012

The Act mandates the National Land Commission to take appropriate action to maintain public land that has endangered or endemic species of flora and fauna, critical habitats or protected areas and to identify ecologically sensitive areas that are within public lands. The Act further requires the commission to undertake an inventory of all land-based natural resources and reserve public land for any purposes, including environmental protection and conservation. The Act further empowers the commission to make rules and regulations for the sustainable conservation of land-based natural resources, including;

1. Measures to protect critical ecosystems and habitats;
2. Incentives for communities and individuals to invest in income-generating natural resource conservation programmes;
3. Measures to facilitate the access, use and co-management of forests, water and other resources by communities who have customary rights to these resources;
4. Procedures for the registration of natural resources in an appropriate register;
5. Procedures on the involvement of stakeholders in the management and utilisation of land-based natural resources
6. Measures to ensure benefit sharing to the affected communities.

3.3.6 The County Governments Act, 2012

The Act elaborates on the county governments' powers, functions and responsibilities and clarifies how the County Governments shall perform their constitutional mandates, which include the implementation of specific government policies on environment and natural resources conservation. Additionally, the Act requires that there shall be a five-year integrated development plan for each county and clarifies that cooperation in planning between the national and county governments shall be done within the context of the Inter-Governmental Relations Act, 2012.

3.3.7 The Wildlife Conservation and Management Act, 2013

This legislation holds significant importance as it empowers the Kenya Wildlife Service (KWS) to establish agreements with other competent authorities to safeguard wildlife and their habitats. Numerous mangrove forests situated in Marine Protected Areas (MPAs), such as the Kiunga Marine National Reserve in Lamu County, fall under the jurisdiction of this Act.

3.3.8 Water Policy, 1999

The Water Policy (1999), seeking to comprehensively deal with the problems of water and sanitation, adopts an integrated approach to water resources management. The policy recognises the inextricable link between the provision of water supply and wastewater disposal and applies various tools for effective management such as effluent discharge standards, permits for water abstraction and disposal, and using economic instruments for water pollution control. It encourages the participation of communities and private institutions in the provision of water supply and sanitation services and makes the role of government regulatory as opposed to the direct provision of services.

3.3.9 Tourism Act, 2012

Lamu PFMP (2022-2026) establishes responsible licensing, classification, regulation, limitation, and control of tourism-related activities and services, as well as natural resource management through climate change adaptation and mitigation guidelines. Mangroves are part of Lamu tourism's products and services; so, developing tourism products and services based on the resource should entail empowering its successful protection and management.

3.3.10 Climate Change Act, 2016 (Amended in 2023)

Mangroves capture more carbon than terrestrial forests, so Lamu mangroves play a greater role in carbon sequestration in Kenya. The Climate Change Act provides policies, strategies, and action plans to protect and coordinate climate change measures through the Climate Change Fund by financing climate-related actions and interventions. It aims to enhance resilience, mitigate climate impacts, and support sustainable development. The Act establishes the **National Climate Change Council**, responsible for overseeing climate action, advising the government, and coordinating national efforts. The Climate Change Act was amended in 2023 to provide guidance in the development and implementation of carbon markets and non-market approaches in compliance with international obligations.

3.3.11 The Carbon Credit Trading and Benefit Sharing Bill, 2023

An act of Parliament to establish a regulatory framework for trading carbon credits and benefit sharing in carbon credit trading in forests gazetted by the Environmental Management and Co-ordination Act, 1999. This is defined as an area area covered by a carbon credit trading permit and includes any area either above or below the land and airspace of the Republic of Kenya including forests, internal and territorial waters and the seabed underlying these waters. The Carbon Credit Trading and Benefit Sharing Bill is in line with the Nagoya Protocol under the convention of Biological Diversity that supports the access and "benefit sharing" meaning the fair and equitable sharing of monetary and non-monetary benefits from the use of natural resources;

3.3.12 Fisheries Management and Development Act, 2016

The Fisheries Act establishes a framework for fisheries development, management, exploitation, usage, and conservation, and it protects fish breeding and feeding grounds through subsidiary legislation. Part V 29 (2) of the conservation push for fisheries should ensure that the resource's user community is not denied the right to benefit from the resource, especially if it is their livelihood source. This is accomplished by encouraging the conservation and management of breeding and feeding grounds for numerous marine fish species, including mangrove forests. It acknowledges the inter-jurisdictional features of maritime fisheries and advocates for collaboration and cooperation in managing fisheries resources.

3.3.13 National Mangrove Ecosystem Management Plan (2017-2027)

The development goal of this management plan is to give specific guidelines for the management and sustainable use of mangrove products and services while improving biodiversity conservation and the health of ecosystems for national and local success. The NMEMP (2017-2027) addresses the lack of ecosystem-based management approaches mandated under Section 47 of the FCMA 2016 for management plan preparation. The development objective of this management plan is to sustain the supply of mangrove goods and services for local and national development. The NMEMP provides for creation of frameworks for its implementation as explained in Chapter 4.

3.3.14 The Integrated Coastal Zone Management Policy 2014 and ICZM Action Plan 2019 -2023

ICZM Policy fulfils the need for an alternative and effective management system that balances development and conservation interests in the coastal zone. There is a need for a policy to guide and ensure a coordinated response to emerging issues such as global warming and climate change, including extreme weather events and other disasters. The ICZM policy framework provides for sustainable development of the coastal zone which will be an important contribution to meeting the goals of Vision 2030 development blueprint to make Kenya a middle-income country.

3.4 Sub-national policies and legislation governing mangrove conservation and biodiversity

County governments play a crucial role in mangrove conservation and management by developing policies and plans linked to national frameworks to deal with specific environmental concerns.

3.4.1 Lamu County Integrated Development Plan (CIDP), 2023-2027

The County Government Act of 2012, Section 104, requires counties to create County Integrated Development Plans (CIDPs) and establish planning units at all administrative levels. The Lamu County Community Integrated Development Plan (CIDP) for 2023-2027 reflects the community's ideas, priorities, and requirements. Mangroves are considered a valuable natural resource in the county. Planting mangroves is an essential component in environmental protection to increase forest cover.

3.4.2 Lamu County Spatial Plan; Volume II (2016 – 2026)

The County Government Act of 2012, Section 110, mandates county spatial plans to guide land use management systems in various counties. In this scenario, Lamu County Spatial Plan Volume 11 (2016-2026) provided action plans in response to a number of emerging projects in the county, including Lamu Port, South Sudan, and Ethiopia Transport (LAPSSET), to mitigate the concerns the projects provide to natural resources, such as Lamu's mangrove. The strategy focuses on protecting mangroves as nurseries for juvenile fish, resolving encroachment issues on mangrove areas, and improving sustainable harvesting of mangroves for their ability to absorb carbon to address emerging climate change issues.

Since the implementation of Participatory Forestry Management Plans (PFMPs) in Kenya in 1997, Community Forest Associations (CFAs) were formed as community-based organisations to co-manage forest resources with national and local government entities. The recognition of CFAs as a legal entity was entrenched in the subsequent forest legislation. Community Forest Association formation and registration guidelines 2009, PFM guidelines 2015 and Participatory Forest Management Plan Development guidelines provide further elaboration for the community.

3.4.3 Lamu Mangrove Participatory Forest Management Plan PFMP (2022-2026)

The Lamu Participatory Forest Management Plan (PFMP 2022-2027) was prepared under section 47(1) of the Forest Management and Conservation Act 2016 with a mandate that states that *"Every public forest, nature reserve and provisional forest shall be managed in accordance with a management plan that complies with the requirements prescribed by Regulations made by the Cabinet Secretary"*. This was done through a consultative process by the adjacent community, represented by **LAMACOFA** community members. Lamu Community Forest Association (LAMACOFA) was established in early 2015 and established on 31st December 2015. The CFA covers 13 villages that are adjacent to mangrove forests, namely Amu, Shela, Manda, Magogoni, Kwa Sasi, Ngiini, Ndununi, Mashundwani, Mokowe, Bandari Salama, Kipungani, Magumba, and Matondoni villages. The vision of the CFA is that '*Mangroves of Lamu are restored and protected for environmental sustainability, national development and community livelihood*.

3.4.4 Mkunumbi Mangrove Participatory Forest Management Plan (In progress)

The Mkunumbi Participatory Forest Management Plan (PFMP) is currently under development and aims to bring together local community groups and various stakeholders for the conservation and sustainable management of mangroves in the Lower Southern Swamp, Lamu. This evolving framework emphasises the collaboration between local communities, government agencies, and conservation organisations to ensure that mangrove ecosystems are protected and restored.

3.5 Identified Gaps in Policy and Legislation

Kenya has many institutions involved in the management of the environment and natural resources. They range from government departments to non-governmental organisations, private sector organisations, associations, community-based organisations, and others. Wetlands cut across the land, forestry, wildlife and water sectors. The wetlands management is handled across different government agencies, i.e. County Governments, Kenya Forest Service, Kenya Wildlife Service, Water resource Authority, National Environment Management Authority, Kenya Marine and Fisheries Research Institute, Kenya Forest Research Institute and Kenya Fisheries Services, among others.

The County Governments are established by the Constitution of Kenya, 2010, while Acts of Parliament establish the other Government agencies with their mandates, roles and responsibilities clearly spelt out. With that range of institutions there is bound to be operational conflicts and duplication of roles and responsibilities. Before the enactment of EMCA in 1999 as an overarching framework, environmental laws were scattered. EMCA devolves administration of a number of environmental and natural resources management issues to communities through County Environment Committees. EMCA 1999 (rev 2015) still is yet to cure the challenges of operational conflicts, duplication of mandates and different legal standards on management of environment and natural resources. The Acts, however, fail to address the intersectionality of their mandates and roles in an ecosystem approach and landscape scale.

Another critical gap in policy and legislation is the benefit-sharing mechanisms emanating from the conservation and protection of natural resources such as wetlands. Despite the high valuation of wetlands in terms of biodiversity and ecosystem services, the communities dependent on wetlands for their sustenance are disenfranchised by bio prospectors and other entities monetising wetlands benefits without commensurate benefits to the communities protecting and preserving the Wetland resource.

Marine parks and reserves are under the jurisdiction of the Kenya Wildlife Service (KWS), whose mandate is to protect and conserve wildlife found in mangrove forests. These marine protected areas encompass important marine habitats, including coral reefs, seagrass beds, and mangrove forests, but they are ecologically and economically dominated by coral reefs. The obligation to enforce laws and regulations related to marine and terrestrial parks and reserves is the responsibility of KWS (Alemayehuet *al.*, 2015). The institution, however, faces limitations when it comes to enough manpower to patrol and exercise power beyond the boundaries of the mangrove reserves and parks. Unplanned development, illegal harvesting of mangroves, and encroachment can occur in areas adjacent to mangroves in marine parks and reserves. The Kenya Wildlife Service (KWS) alone cannot stop unplanned development near the High-Water Mark (HWM) or encroachment in the mangrove forest by private developers. In such instances, KWS must work with several institutions like the Kenya Forest Service and The National Environment Management Authority to address these challenges.

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Chapter 4: Socio-cultural, Institutional, Historical and Political Context of Lamu Southern Swamp Mangroves

Mangroves of Lamu have historically played a pivotal role in the socio-economic development of this region (Idha, 1998). This section synthesises existing literature to illuminate the socio-cultural, institutional, historical and political dimensions that influence the conservation and management of mangroves in the Lamu Southern swamp. The review also included qualitative descriptions and quantitative indicators of development trends such as significant demographic changes, patterns of asset ownership and livelihoods, external political or economic environment. Household surveys were conducted in five villages selected based on their proximity to the mangroves of the Lamu Southern swamp, representing all sites within the study area. Interviews were done in Mkunumbi (24), Mea (18), Manda Maweni (26), Mokowe (22), and Matondoni (20). Moreover, one key informant (KI) interview was conducted each in Mkunumbi, Mea, Manda Maweni, and Matondoni.

4.1 Socio -Cultural Context

The mangroves of Lamu have played a crucial role in shaping the socio-cultural and economic landscape of the region for centuries. The coastal populations, including the Swahili and Bajuni communities, have long relied on mangrove ecosystems for subsistence, construction, and cultural practices. This deep reliance has shaped not only the economic structure of the region but also its social, spiritual, and architectural heritage (Idha, 1998; Pulver & Siravo, 1986).

Historically, the relationship between the mangroves and the local population has been deeply intertwined with maritime trade and cultural exchanges. Evidence suggests that the Indian Ocean maritime trading network expanded to the East African coast as early as the 2nd century BC, with the earliest mention of the Lamu archipelago found in the Periplus of the Erythraean Sea, a Greek guide from the 2^{nd} to 3^{rd} century AD. Studies highlight the export of mangrove poles, palm oil, ivory, and other goods, indicating that Lamu was a significant trading hub where dhows from Arabia, the Persian Gulf, India, and even Southeast Asia docked to exchange wares (Idha, 1998). This trade fostered economic growth in Lamu and contributed to the development of the coastal Swahili civilization, which engaged in fishing, boat building, and sea-based trade (Idha, 1998). Lamu's strategic position as a trading hub and its vibrant interaction with different cultures influenced its socio-cultural evolution (Abungu, 1994). For centuries, it has been a hub of intercultural, socio-political, and economic exchanges along Africa's east coast. These interactions are reflected in the blend of cultures and languages, religious practices, architectural and artistic influences, and a fusion of cuisine shaped by local traditions as well as Arabian, Indian, Chinese, and European influences (Laher, 2011).

Mangroves are deeply embedded in the Swahili cultural heritage, especially through their extensive use in the construction of homes, mosques, and traditional dhows (boats). Species such as *R. mucronata* and *C. tagal* have been historically utilized due to their strength and durability, making them invaluable for both domestic and maritime architecture (Idha, 1998).

The socio-economic structure of Lamu was historically stratified, consisting of a three-tiered system: 1) at the top were the land-owning noblemen (*waungwana*), who were the free-born; 2) in the middle were the majority of the population called *wazalia*, descendants of slaves who were treated as inferior members of the community by the *waungwana*; and 3) at the bottom were the slaves (*watumwa*), who, together with the *wazalia*, performed most of the difficult manual labor, such as mangrove pole cutting, fishing, dhow building, domestic service, and agricultural or industrial work (Martin & Ryan, 1980; Brown, 1988). Following the legal emancipation of slaves in 1907, many former slaves fled plantations and settled in areas like Mkunumbi, establishing new communities and transitioning from servitude to self-sufficiency (Curtin, 1985; Romero, 1986). This demographic shift contributed to a population that ranged between 5,000 and 7,000, comprising various clans with diverse ethnic origins, including those from the African mainland, the Arabian Peninsula, Persia, India, and beyond (Brown, 1988).

Mangroves have been vital not only for economic activities but also for cultural practices. The local population has long relied on mangroves for subsistence, utilizing species like *R. mucronata* and *C. tagal* for constructing homes, mosques, and traditional dhows. This architectural heritage reflects the cultural continuity of the Swahili people, who have historically engaged in shipbuilding and fishing, skills enhanced through cultural exchanges with Arab and Asian traders (Idha, 1998; Pulver & Siravo, 1986). In addition to their critical role in construction and trade, mangroves support other vital activities, with fishing being one of the primary economic practices in Lamu. Many households depend on the surrounding mangrove ecosystems for their livelihoods. Mangroves contribute to honey collection, furniture making, fishing gear production, and the creation of dyes, as well as providing medicinal benefits, with specific species being used to treat various ailments (Hamza, 2022). Mangroves are also highly valued for construction, fuelwood, and their role in supporting wild fish populations, reinforcing their economic and cultural importance in the region. As such, the reliance on mangroves for various traditional crafts and trades has shaped the identity and cultural practices of the Lamu people (Idha, 1998).

Although mangrove cutting was primarily initiated by islanders (mostly Bajuni) using their vessels during the northeast monsoon season, this industry had minimal impact on mainland communities, as it did not disrupt their agricultural or pastoral activities (Ylvisaker, 1975). By the late 1960s, mangrove poles were a significant source of income for Lamu, ranking fifth after cotton, charcoal, coconut oil, and fish (Idha, 1998). However, the export of mangrove poles faced challenges, culminating in a government ban in 1982, which was met with deep resentment from the local population. This ban was perceived as another attempt to deprive locals of their livelihoods, especially as they had come to rely heavily on mangroves due to declines in other economic sectors (Idha, 1998).

The socio-economic decline of Lamu was exacerbated by colonial policies that curtailed local economic rights and land ownership, leading to increased poverty and dependence on mangroves and fishing (Idha, 1998). By the 1920s, the population of Lamu District had significantly decreased, reflecting the economic downturn and the exodus of people seeking work in urban centers like Mombasa (Idha, 1998). Today, Lamu remains one of the poorest and most marginalized areas in Kenya, with major economic activities including agriculture, fishing, mangrove cutting, livestock production, and tourism. These sectors employ over 80% of Lamu's total labor force (Lamu CIDP, 2023).

Most residents are Sunni Muslims, with smaller communities of Christians and Animists also present (Laher, 2011). The major ethnic groups include the Bajuni, Pokomo, and Arabs, with smaller populations of Mijikenda, Taita, and Somalis (See section on demographic patterns below). Additionally, Kikuyu from mainland Kenya were settled through government schemes beginning in 1976. The region is also home to white Kenyans, Europeans, Americans, Israelis, and Arabs, many of whom are involved in the tourism industry or reside on Lamu Island seasonally. Most of the indigenous residents are rural, while a small minority, live in towns such as Lamu, Mpeketoni, Mkunumbi, Witu, Hindi, Kiunga, Faza, Siyu, Pandaguo, and a few others (Laher, 2011).

Mangrove exploitation in Lamu has traditionally followed sustainable practices that were passed down through generations. There is a nuanced relationship between the modern and the ancient with the presence of old and new influences on the lifestyle of indigenous people (Laher, 2011). Islanders initiated the industry, utilizing island-owned vessels and living aboard while working in the sea creeks (Ylvisaker, 1979). The crews, often composed of Bajuni cultivators, practiced selective harvesting where only mature and straight mangrove poles were cut, allowing younger trees to grow and regenerate (Pulver & Siravo, 1986). This careful approach ensured that the mangrove forests would continue to provide for future generations (Lamu County Government, 2018). Furthermore, while Lamu's population predominantly follows Islamic teachings, local traditions associated with mangroves have persisted. Interviews with locals revealed that certain myths, taboos, and rituals are associated with mangrove areas (See section on myths, taboos and rituals below), highlighting their cultural importance beyond economic use (Rönnbäck*et al.,* 2007). Mangroves were not only vital for construction but also held spiritual significance, with sacred areas often linked to healing and protection from evil spirits (Hamza, 2022).

Mangrove exploitation in Lamu has also been a gendered activity. Men have traditionally been responsible for harvesting mangroves and engaging in fishing, while women played key roles in processing and selling fish and other products derived from mangroves (Ahmed *et al.,* 2023b). This division of labor reflects the broader societal structure in Lamu, underscoring the critical contributions of both men and women to the sustainability of mangrove ecosystems.

Lamu's socio-cultural context has been profoundly shaped by Islamic influences, particularly in its urban planning and architecture. As a major center for Islamic learning and Swahili scholarship, Lamu became an important hub for religious education and trade (Wanderi, 2019). The integration of mangrove wood into Swahili architecture, such as the construction of homes and mosques, reflects the ongoing cultural continuity that ties the community to its environment (Wiggins, 2010). The artistic traditions of the region, such as woodcarving, calligraphy, and boat building, are essential in preserving Lamu's rich cultural fabric, with mangrove wood being central to these crafts (Gok, 2017; Lamu CIDP, 2023).

Rapid population growth and the increasing demand for mangrove resources have disrupted the traditional balance between sustainable practices and modern economic pressures. According to the 2019 Census, Lamu's population grew to 143,920, with many residents living in rural areas where traditional livelihoods like fishing and mangrove cutting are still dominant (Lamu CIDP, 2023). The youth bulge and limited employment opportunities have exacerbated pressure on mangroves, threatening both the environment and the cultural practices tied to these ecosystems (Idha, 1998).

Government-imposed restrictions, such as the 1982 ban on mangrove exports, were introduced to curb deforestation and conserve mangrove forests. However, these restrictions generated tensions between the need for environmental conservation and the livelihoods of local communities, many of whom continue to rely heavily on mangrove resources (Idha, 1998). This has highlighted the need for alternative income-generating activities and renewed efforts to integrate traditional knowledge into modern conservation strategies. However, the decline in economic opportunities due to external factors, such as the export ban and recent security issues, has led to a resurgence of ancient crafts, as communities strive to maintain their cultural heritage while adapting to changing circumstances (Idha, 1998).

In recent years, there has been a revival of traditional practices, particularly through the promotion of ecotourism. Lamu’s cultural heritage, closely tied to its coastal environment and mangrove forests, has become a focal point for ecotourism initiatives. These efforts aim to showcase Lamu’s unique cultural and environmental identity while providing alternative livelihoods that reduce the pressure on mangrove resources (Rönnbäck *et al.*, 2007). Ecotourism not only helps preserve the traditional crafts and livelihoods associated with mangroves but also encourages sustainable use of these critical ecosystems.

The construction of the international port presents a potential turning point for Lamu's socio-cultural landscape, promising much-needed jobs and economic development (Hillewaert, 2019). This development could revitalise the local economy and provide new opportunities for the community, allowing them to reconnect with their historical maritime roots while fostering a sustainable future.

4.1.1 Myths, Rituals, and Taboos

Based on household and key informant interviews, the study reveals that communities across various sites in Mkunumbi shared a wide array of myths, rituals, and prohibitions that reflect their deep connection to the mangrove forests. These cultural beliefs and practices played a crucial role in promoting the sustainable use and conservation of the ecosystem. The traditions illustrate how the communities' spiritual and cultural values shaped their relationship with the mangroves, fostering ecological stewardship and guiding conservation efforts. The spiritual, cultural, and ecological practices were closely intertwined with their interactions with the mangroves, helping to maintain both social and spiritual order while advancing environmental protection. This seamless integration of beliefs ensured the sustainable use and preservation of the mangrove ecosystem for future generations. However, most respondents claimed they were unaware of the existence of the myths, rituals, and taboos surrounding the mangrove ecosystem (Table 1).

Table 1 Proportion of respondents in each village who claimed they had no idea whether myths, rituals and taboos existed

Attribute	**Village**				
	Manda Maweni (n=26)	**Matondoni (n=20)**	**Mea (n=18)**	**Mkunumbi (n=24)**	**Mokowe (n=22)**
Taboos/prohibitions	84.21	67.16	56.76	62.30	64.58
Whether traditional knowledge was used in the past in mangrove conservation	82.46	74.63	62.16	59.02	62.50
Whether there are sites used for conducting customs or rituals in mangroves	80.70	71.43	65.79	71.67	77.08

Cultural Beliefs and Practices: The communities had strong cultural beliefs that intertwined the mangrove forests with their heritage, spirituality, and livelihoods. In Manda Maweni, the mangroves were viewed as part of the community’s heritage, providing various benefits to both locals and the government. In Matondoni, it was believed that dumping trash into the ocean at specific times (1:00 p.m. and 11:00 p.m.) could cause harm, such as miscarriages in pregnant women or illness in men. In Mea, people were advised to fish in large groups, as it was believed that no fish would be caught otherwise. Similarly, in Mkunumbi, collective responsibility was emphasized, and the community stressed the importance of avoiding the destruction of the forest. In Mokowe, the mangroves were considered a vital source of income, providing fish and bees for the community.

Mythological beliefs: In Manda Maweni, it was believed that the mangroves were inhabited by spirits, including mermaids (*vitunusi*). Similar beliefs were found in Matondoni, where people feared encountering ghosts (*viganga*) in the mangroves at specific times, particularly at 1:00 p.m. Likewise, in Mea and Mokowe, the mangroves were thought to be inhabited by spirits such as ngoloko and mermaids.

Rituals played a role in how these communities interacted with the mangrove forests. In Manda Maweni, it was reported that elders performed rituals and worship in sacred areas within the mangroves. In Mokowe, it was also reported that sacrifices were offered to spirits, and women in their menstrual periods were not allowed to enter the forest as part of these spiritual observances.

Many ***taboos*** shaped behaviour within the mangroves. In Manda Maweni, conducting transactions in the mangrove ecosystem on Fridays was prohibited. In Matondoni, certain areas like Kisisi were avoided due to the belief that they were haunted by ghosts. Dumping trash into the ocean was forbidden, and littering in the mangroves was strictly prohibited in both Matondoni and Mokowe. People were discouraged from entering the mangrove forest alone, past midnight, or during high tide in all sites (Manda Maweni, Matondoni, Mea, Mkunumbi, and Mokowe). In Mkunumbi, urinating in the mangroves was strictly forbidden, as was working in the mangroves on Fridays. In Mea, women were advised not to go fishing in the ocean, as it was considered bad luck. Across all sites, young and large mangrove trees were protected from being cut down. In Matondoni, people were warned not to enter the mangroves at night to avoid ghosts and were instructed not to call out names, eat, or picket while inside the forest. Additionally, people in Mokowe were advised to avoid using perfumes or entering the forest if they were blemished. Across Matondoni, Mea, and Mkunumbi, women on their periods and children were prohibited from entering the mangroves.

Totemism and Sacred Geography: While not explicitly stated as totemism, the reverence shown toward the mangroves suggests a totemic relationship between the communities and the forests. In Manda Maweni, mangroves were considered part of the community's heritage, while in Mokowe, they were seen as central to the community’s identity due to their economic and cultural significance. The communities also demonstrated a deep sense of sacred geography. In Manda Maweni, specific places within the mangroves were used as sacred sites for rituals and worship. In Mkunumbi, certain times especially towards the end of August, were designated as inappropriate for cutting mangroves, reflecting the connection between time and the spiritual significance of the forest.

Sustainability: Many of the communities had practices that reflected a sustainable relationship with the environment. In Manda Maweni, Mea, and Mkunumbi, the belief that mangroves regenerated on their own revealed an understanding of natural ecological cycles. In Mkunumbi, there were strict prohibitions on collecting items from the sea and cutting trees indiscriminately, aimed at protecting the environment. In Mokowe, the community recognized that mangroves did not grow well in areas with high salinity, highlighting their awareness of the environmental conditions necessary for mangrove growth.

4.2 Institutional Context

Stakeholders play various roles in managing Lamu mangrove ecosystem resources. Collaboration across several sectors and stakeholders is necessary for mangrove governance. Establishing institutional frameworks, game rules, a defined tenure regime, stakeholder rights and obligations are all necessary for effective mangrove management. The important stakeholders comprise; county government, local community groups, government institutions, non-government organisations, and research institutions. Effective management of the complex mangrove ecosystem requires accurate situation analysis, management plans to address landscape issues and policy and legal frameworks. Due to the interdependencies with other resources, the legal entities tasked with overseeing these resources must operate in tandem. Recognizing the many laws, regulations, and policies that outline procedures or factors to be taken into account for managing mangrove forests is part of this strategy (Wanderi, 2019).

The engagement of multi-stakeholders helps in coordination of policies across sectors in conservation and management of mangrove forest ecosystems (Huxham*et al.,* 2015). Public participation increases confidence and enthusiasm in mangrove forest conservation and provides a focus for construction of common perspectives, agreed on solutions and interactions to reach consensus regarding the set objectives (Holmes & Scoones, 2000). Kenya Marine and Fisheries Research Institute (KMFRI) has over the years spearheaded research on rehabilitation, conservation and sustainable utilization of mangroves in Kenya. The institute coordinated the development of Kenya's National Mangrove Ecosystem Management Plan (2017-2027). The plan provides a road map towards sustainable management of the mangrove ecosystem for national development and enhanced livelihoods. The National Mangrove Ecosystem Management Plan established the National Mangrove

Management Committee and the County Mangrove Management Committees to support implementation of the Plan.

The Lamu County Mangrove Management Committee has established a platform for engagement of mangrove stakeholders, reporting of interventions contributing to the implementation of the National Mangrove Ecosystem Management Plan (Figure 4). The Committee is supporting the Kenya Forest Service in building synergy of stakeholders' interventions in the Lamu Mangrove Ecosystem.

Figure 4: The Institutional Framework for Implementation of the National Mangrove Ecosystem Management Plan

The National Museums of Kenya (NMK) has also been active in promoting the conservation of Lamu's cultural heritage, including advocating for the use of traditional materials such as mangrove poles in the restoration of historic buildings. Although collaborative approaches have been implemented in the management of mangroves, governance problems arising from conflicting or ambiguous policy objectives are present at various levels of government institutions. This has led to inconsistent management decisions, including inadequate law enforcement, corruption, and conflicting mandates between conservation and development objectives, ultimately undermining the protection of mangrove ecosystems.

Insecure tenure and the position of communities in the area have led to a mistrust of potential partners (USAID, 2009). Illegal and informal transactions involving islands and beach plots have fuelled resentment toward outside individuals and groups, limiting future opportunities for communities to establish effective partnerships for natural resource management (NRM) and income generation. Additionally, there is a widespread perception that previous projects have failed to fulfil their promises (USAID, 2009). Therefore, at the local level, the involvement of the Community has been critical in promoting sustainable use of mangroves. However, the lack of formal land tenure rights for many local communities complicates their participation in conservation initiatives. Without clear ownership, communities often engage in unsustainable harvesting practices out of economic necessity, as the alternative livelihoods promoted by the government are insufficient to meet the growing demand for resources. The management of Mangroves up to 2005, took a top-down approach where the government directly managed forests through policing. However, in the subsequent review of the Forest Act, communities are allowed to manage forests adjacent to them through CFAs, thus providing a legal framework for Participatory Forest Management (PFM) (Forest Conservation and Management Act, 2016; Ahmed *et al.,* 2023b).

Including local communities in decision-making is a critical component of sustainable mangrove management (Roslinda *et al.,* 2021). Notably, community participation is essential for sustainable mangrove ecosystems, as mangroves are closely related to local community livelihoods. Thus, the concept of community-based mangrove management has become essential due to the precarious state of mangrove ecosystems and the widespread adoption of decentralized governance practices in many developing countries (Arifanti *et al.,* 2022).

4.3 Historical Context

Lamu town was an ancient island port with a mainland hinterland. It had become an independent city-state before the early eighteenth century, and by the late 1820s, the Sultan of Oman, established a protectorate over Lamu at the invitation of the town elders (Romero, 1986). The area was a cultivated area under the control of the Lamu Afro-Arabs landowners in the late nineteenth century. Slavery permeated all aspects of life, from agriculture to town labour with the Afro-Arabs being dependent on their slaves for profits and luxuries then (Romero, 1986). During this time, the several small villages in Mkunumbi and Mokowe were composed of about seven or eight or eight families each - including several wives in each family - and each was controlled by its council of elders (Curtin, 1985). When it was deserted after the mainland slaves were emancipated in 1907, the nomadic pastoralists such as the Kore drifted further South into the fringes of the study area (southern swamps) and later to Mokowe and Lamu in the 1920s (Romero, 1986). The Indian ship owners dominated slave transportation, with ships carrying slaves to Arabia, India, and the Red Sea ports (Curtin, 1986).

During this time, mangrove poles were a cornerstone of Lamu's economy and culture for over 2,000 years. Reports indicate that mangroves were an economic resource even before the 1890s, and by the 1900s hundreds of thousands of poles were harvested involving considerable fleets of dhows (Curtin, 1981). Every year, ships and dhows from the Red Sea and the Persian Gulf arrived with the northeast monsoon to pick up mangrove poles (Pulver & Siravo, 1986). This trade helped foster the rise of a prosperous Swahili civilisation at the coast, with Lamu being a hub for maritime activities including dhow building, fishing, and mangrove cutting (Idha, 1998). Reports indicate that mangroves have been exploited for building poles since before the 9th Century AD (Horton, 1986), with tannins for export since the 1890s (Chapman, 1975), and lime for house construction since the 14th century. Additionally, mangroves were used for charcoal and firewood, dhow building, and making traditional fishing traps, net floats, and furniture, apart from their economic contribution to fishing by the ecosystem (Idha, 1998).

Despite the Afro-Arab wealth decline after emancipation in 1907, Lamu exported mainland products such as ivory and hides, as well as ambergris, dried fish, mangrove poles, coconuts, and other items, with a significant influx of dhows reported at the port between 1911 and 1916 (Romero, 1986). As such, by the late 19th century, mangrove cutting had become a significant economic activity in Lamu, contributing heavily to exports to Arabia and the Persian Gulf. However, the ban on the export of mangrove poles and charcoal led to a considerable decline in the economic status of the dependent populations, resulting in increased poverty and marginalization (Idha, 1998). Therefore, the economy of the mangrove-dependent communities of Lamu has experienced transformation throughout history, particularly due to the colonial government's abolition of its slave-based economy in 1907 and shifts in the political and social structure (Hillewaert, 2019). This transformation forced the once-wealthy Swahili to pursue ancient crafts and trades like fishing and mangrove cutting (Idha, 1998).

The main blow to the local community came in 1947 when in an unpopular move, the colonial government took strict control of mangrove exploitation and granted concession (Abuodha & Kairo, 2001) to Messrs. Denhardt & Co., a German firm, to exploit mangrove poles and bark in Lamu, Ngomeni and Vanga (Idha, 1998). Its activities ceased at the beginning of World War 1 and its role was taken by Smith, Mackenzie and Company to exploit mangrove products in the district. Local communities were denied their ancient economic rights which led to economic stagnation of Lamu and heightened poverty leading to migration by people to seek employment in Mombasa and residents to become highly reliant on mangroves for fishing. Between 1947 and 1956, Forestry officials tried to maximise exports by allowing massive cutting of poles due to the discovery of oil in Arabia, but from 1957 onwards, strict quotas were imposed to allow poles to regenerate (Idha, 1998). However, the colonial government introduced concessionaires for poles, bark and firewood which heavily impacted the economic status of *jahazi* captains and their crew (who were mostly Bajuni) to the point of becoming wage earners for the Europeans and Indians.

Reports of overharvesting and the attempted exportation of poles of poor quality prompted the then Forest Department to develop a conservation plan (quotas) beginning in 1950 for each mangrove swamp, including the study site, to be cut each year in a twenty-year cycle to guarantee a continuous yield with local (Curtin, 1981). Reports from the Forestry Department indicated that the poles cut for export by 1934 were crooked and smaller, with no useful bark (Idha, 1998). As such, this plan included yearly cutting of large trees (*nguzo*), firewood and charcoal cutters, and limited cutting of smaller-sized poles to meet local demand. It also included grading poles and restricting cutting to defined areas each year to produce a continuous yield (Idha, 1998). In 1975, the Government of Kenya imposed a ban on the use of mangrove poles for charcoal production. However, the 1960s surge in demand for charcoal led to increased mangrove cutting, rendering the 1975 ban on charcoal export ineffective in curbing mangrove depletion in the study site and in other mangrove swamps in Lamu, until the subsequent ban on pole exportation in 1982 (Curtin, 1981).

Most of the trees cut and exported until the 1970s were *boriti* (butt size 11.5 - 14 cm) and *mazio* (butt size 7.5 - 11.5 cm) (Curtin, 1981). However, the decline in this sector began with a series of abortive regulatory attempts, culminating in the Kenyan government's 1982 ban on the export of mangrove poles due to environmental concerns. This ban, while intended to protect the degrading mangrove ecosystem, was perceived by locals as a direct attack on their livelihoods (Idha, 1998). At the time, many in Lamu had not transitioned to alternative income-generating activities and remained heavily reliant on mangrove exploitation due to the downturn in other sectors of the economy, such as fishing and tourism. The inability to access alternative livelihood opportunities only deepened the economic hardship of the local population. As a result, the ban fuelled resentment, as it appeared to be an imposed external measure that overlooked the socio-economic realities of the coastal communities, further marginalizing a population already struggling with economic instability (Idha, 1998).

Despite the 1982 ban, the average harvest per year remained constant (31734 scores) until 1983. In 1992, the Forest Department licensed the extraction of 72,100 scores of poles in Lamu for domestic use annually. This was based on the national demand of mangrove wood products (Abuodha & Kairo, 2001). However, in 2018, the Kenyan cabinet secretary for environment and forests imposed a ban on mangrove harvesting to increase forest cover and curb illegal logging, but this ban was partially lifted in 2019 in Lamu County, where mangrove harvesting is a key livelihood activity (Kamau *et al.*, 2024).

Despite facing economic decline under British colonial rule, Lamu suffered further setbacks when a government ban on the international mangrove trade severed its economic ties with the Arab world, extinguishing its main source of economic sustenance (Hillewaert, 2019). Recent events, including terrorist activities in the area, have further undermined the already unstable economy of the island. International travel warnings have resulted in a significant absence of tourists in Lamu and the closure of several hotels (Hillewaert, 2019) due to terrorism and the COVID-19 pandemic.

4.4 External Political and/or Economic Environment

Historically, since the colonial period, customary laws/rights were not recognised in the management of natural resources including land, water and forest, rather the mandate was vested in the national government (Njonjo, 2002). This has left Lamu County marginalized with limited infrastructure development and economic opportunities (Willis & Mwakimako, 2021). All long-established indigenous communities including the Boni and Bajuni, were considered "squatters" as they don’t possess title deeds on their ancestral ground since their customary rights were not recognized by the statute of the government territory (USAID, 2009). Additionally, the indigenous communities were historically marginalized politically and economically by Arabs and other ‘outside’ political elites (Mosley & Watson, 2016). Therefore, a chronic trauma exists in Lamu that reaches back to colonialism and extends to the current era, and is characterised by feelings of displacement, dispossession and alienation (Laher, 2011).

The establishment of the forest reserves and the Shifta conflict seemed to have caused the local populations to be displaced in the 1960s and 1970s, there hasn't been any further displacement (Okoth-Ogendo, 1978). Removal of reserved resource rights and customary land is still done without compensation. Some internally displaced individuals from the Shifta conflict have yet to return to their native lands and are still living in Lamu and other towns and metropolitan areas. Other land tenure regimes that exist in Lamu include settlement plans that are purportedly for the impoverished landless but have historically been utilised to settle non-coastal communities (Chome, 2020). Because of the expensive and extremely centralised process for getting titles on government property, residents become resentful as outside organisations secure freehold titles on these grounds while they are unable to obtain titles to ancestral holdings. The situation, causing significant anxiety and instability among residents, is worsened by wealthy and politically connected individuals who have acquired large tracts of land (Laher, 2011).

With a rise in outside participation in local government, settlement plans are lessening the power of long-term inhabitants to address local concerns. Due to their national reserve status, KWS retains legal jurisdiction to administer marine and forest reserves. County councils lack legal power over coastal regions, both within and outside reserves, due to their government land status (Njonjo, 2002). Little indication of land use planning has been found thus far, both inside and outside of the reserves. When land use plans are developed for reserves, resident communities claim that they are not consulted when making decisions about land use, even if they are not always carried out. Residents of the Boni and Bajuni populations follow customary usage guidelines regarding fishing, shifting agriculture, and mangrove harvesting next to park areas (Nyamanga, 2000). Due in part to the area's remoteness and low population density, these laws governing the use of land and resources aside from prohibiting certain activities within the reserves are not being contested by outsiders. However, as land and resource rights are not established, they may be contested if unlawful land deals persist (USAID, 2009).

As a result of land tenure issues, the region has fallen behind in terms of development and is frequently marked by elevated levels of insecurity, poverty, political instability, unemployment, and inadequate infrastructure. Political instability and insecurity, including terrorist activities in the region, have further undermined Lamu’s economy, particularly its tourism industry. The closure of hotels and a decline in tourists' visits have reduced sources of livelihoods for the indigenous people. This has led to increased reliance on natural resources, including mangroves, as alternative sources of income resulting in the unsustainable exploitation of the mangrove ecosystem. Similarly, large-scale land acquisitions for infrastructure and tourism projects have displaced local communities and disrupted traditional livelihoods.

Lamu County is rich in natural resources that support economic development, including over 550 km^2 of arable land, vast tracts of natural forest, a diverse range of fauna and flora, abundant marine resources, and mineral deposits, including oil and gas (NEMA, 2017). It is estimated that over 80% of the communities in Lamu county depend on mangrove as a source of income (Lamu County Integrated Development Plan, 2018). This may be through direct mangrove exploitation (for fuelwood and construction poles) or fishing. However, the sustainability of these activities is in question as overharvesting and governance failures contribute to the degradation of mangrove forests. For instance, commercialisation of mangrove poles fostered a good diplomatic relation between East Africa and the Arab kingdoms devoid of trees (Mohamed *et al.*, 2009). Kenya was exporting an average of 24,150 scores, that's, 483,000 poles (1 score = 20 poles) of mangrove poles annually from Lamu alone at the start of the 20th century. This export averaged 709,026 poles between 1941 and 1956 but dropped to 275,488 poles in the 1991–1996 period. This was far beyond the sustainable level. In 1997, a nationwide ban on the export of mangrove poles was imposed, following a presidential restriction in 1982 due to the increasing trend of deforestation (Mohamed *et al.*,2009; GoK, 2017). The move was met with considerable opposition in Lamu, as anticipated. It was perceived as just one more effort in a long line to deprive the people of their means of livelihood (Idha, 1998).

Similarly, in 1987, the Lamu Town Conservation Project was initiated by the National Museums of Kenya (NMK), which saw Lamu Town and other monuments in the district become National Monuments and later on world heritage in 2001 (UNESCO). This was to preserve ancient structures and monuments, to retain the traditional function of Lamu town. NMK further promoted the use of traditional mangrove materials like construction poles and lime. However, while they enjoyed the support of various developmental organisations on the move to allow locals to exploit mangroves, the state was adamant and only advocated for strict regulation and complete conservation of mangroves (Idha, 1998).

In the past ten years, after the adoption of the 2010 constitution, there has been significant economic development in this area due to the transfer of power and access to county government. The Port-South Sudan-Ethiopia-Transport (LAPSSET) Corridor, launched in 2012, is a major infrastructure project that promises economic development (Chome, 2020; Gambino & Reboredo, 2024). However, this poses a serious environmental threat to mangrove ecosystems through massive destruction of mangrove for channel expansion (Lamu County Integrated Development Plan, 2018). Lamu's mangroves remain a critical ecosystem/resource for the local livelihood. The local communities depend on mangrove for fishing, harvesting firewood, construction material and other services. This sector employs over 80% of Lamu’s workforce (Lamu County Integrated Development Plan, 2018) . However, the sustainability of these activities is in question as overharvesting and governance failures contribute to the degradation of mangrove forests. Ultimately this will have an impact on the culture and natural environment.

The infrastructure development is already underway with indications of significant impact on the ecosystems through clearance (Wanderi, 2019). Critics worry that the project will raise the likelihood of violence, destroy marine habitats that are vital to local livelihoods, aggravate decades of marginalisation, and displace tens of thousands of people from Lamu (Lamu sensitivity atlas). The fight against the occupation and development started as preventive resistance led by the fishermen, local and international non-governmental organisations, indigenous communities, landless peasants, pastoralists, and marginalised ethnic groups, primarily the Bajuni and Orma (NEMA, 2017). Among the methods of mobilisation were the creation of a network or collective action, legal actions, court proceedings, judicial activism, protests against EIA officials, letters and petitions of complaint, public campaigns, and street demonstrations and matches (Human Rights Watch, 2018).

4.5 **Demographic patterns**

According to the 2009 Kenya Population Census, Lamu's population was estimated at 101,539, comprising 53,045 males and 48,494 females with 27.4% of the population living in the urban areas. By the 2019 Census, the population had grown to 143,920, with 76,103 men and 67,813 women. The total population in the county was only 71,215 in 1999. In 1999, 36.3% of the population were monetarily poor, while in 2019, 30% of the population were monetarily poor. While Lamu County is endowed with various resources, including beaches, forests, and historical heritage sites, it faces significant challenges, such as high youth unemployment rates, elevated poverty levels, and limited access to basic services like water, food, and shelter (NEMA, 2017). Population projections indicate that by 2027, the population in this Sub-County would have increased by 28.41%. As such, it is expected that the proportion of the monetarily poor population would increase.

The county covers an area of 6,283 km^2 and is sparsely populated, with a population density of 23 persons per km^2. It is one of the top counties in Kenya with the highest propensity for in-migration (49.2%). There are 37,963 households in the county, with approximately 72.39% of the population residing in rural areas (Census, 2019). The population of Southern Swamp was estimated at 76,672 (Table 2; Census, 2019). The 2019 census data on the population distribution by age and sex indicates that Lamu West Sub-County has a predominantly young population. According to the data, 37.65% of males and 36.10% of females are children aged 0 to 14 years. Additionally, 36.02% of males and 31.00% of females are youths aged 15 to 34 years. The data further reveals that 20.8% of males and 16.63% of females are middle-aged, between 35 and 59 years, while the remaining population consists of the elderly.

Table 2: Distribution of population by sex, households, land area, and population density in the study area.

Location	**Male**	**Female**	**No. of Households**	**Land area (km^2)**	**Density (Persons/km^2)**
Mokowe	4,598	3,259	2,859	75.6	104
Mkunumbi	6,703	6,050	3,323	691.4	18
Shela/Manda	2,083	1,621	1,095	52.9	70
Mkomani	4,406	3,994	2,065	3.5	2,388
Matondoni	1,326	1,215	576	31.6	80
Langoni	6,617	6,769	3,343	11.5	1,167
Amu	14,432	13,599	7,079	99.5	282
Total	**40,165**	**36,507**	**20,340**	**966**	

The low population in Lamu is due to insecurity issues, harsh climatic conditions and poor infrastructure (GoK, 2017). Other challenges include insufficient social services like education and healthcare, poor land management, poor communication networks and food insecurity. Population distribution within Lamu County is also influenced by access to economic activities like agriculture, livestock keeping, fishing and trade due to these more than 50% of the Lamu County population lives in Amu and Mpeketoni in Lamu West Constituency (Lamu CIDP, 2013), this makes Amu to be highly populated compared to other sublocations in the Southern swamp as shown in Table 2. The low population in Manda and Matondoni might be due to poor quality soil since they are the main sites for sand and ballast quarrying (Lamu CIDP, 2023).

Table 3 below shows the demographic characteristics of the respondents interviewed in the study area by gender, age and religion. Household survey interview data revealed that most of the respondents interviewed in Manda Maweni (71.7%), Mea (56.5%), Mkunumbi (75.0%) and Mokowe (57.9%) were men. Most of the respondents in Manda Maweni (46.4%), Matondoni (55.0%), Mea (43.5%) and Mokowe (47.4%) were aged between 18-35. Furthermore, most of the respondents in Matondoni (90.0%), Mea (43.5%), Mkunumbi (100%), and Mokowe (89.5%) were Muslims.

Table 3: Demographic characteristics of respondents in the study area by gender, age, and religion

Characteristic	**Categories**	**Proportion of respondents (%)**				
		Manda Maweni (n=26)	**Matondoni (n=20)**	**Mea (n=18)**	**Mkunumbi (n=24)**	**Mokowe (n=22)**
Gender	Female	28.6	70.0	43.5	25.0	42.1
	Male	71.4	30.0	56.5	75.0	57.9
Age group	18-35	46.4	55.0	43.5	37.5	47.4
	36-55	32.1	25.0	39.1	54.2	26.3
	Above 55	21.4	20.0	17.4	8.3	26.3
Religion	Christian	82.1	10.0	43.5	0.0	10.5
	Muslim	17.9	90.0	43.5	100.0	89.5
	None	0.0	0.0	13.0	0.0	0.0

The inhabitants of Lamu County are culturally diverse with different ethnic groups. The indigenous ethnic groups are Bajun, Swahili, Sanye, Aweer (Boni) and Orma with Banju being the largest. Each of the ethnic groups has a distinct culture. Recently other communities like Giriama, Pokomo, other Mijikenda subtribes and other communities have migrated to Lamu County in search of different opportunities that are available there (Lamu County Government, 2018).

Interviews with respondents across the study site revealed that there are currently 15 ethnic groups including the Bajun, Boni, Borana, Digo, Giriama, Gunya, Kamba, Kikuyu, Kisii, Luhya, Luo, Orma, Sanye, Somali, and Taita (Table 4). Manda Maweni was the most diverse with 8 ethnic groups followed by Mokowe with 7 ethnic groups, Mea with 6 ethnic groups, Mkunumbi with 4 ethnic groups and Matondoni with only 2 ethnic groups. Bajun was common across five villages and dominated Matondoni with 95% of respondents, Mkunumbi 75.0% and Mokowe 57.9%. Conversely, Manda Maweni was dominated by the Luo ethnic group representing 35.7% of the respondents and Mea was dominated by Kikuyu contributing to 43.5% of the respondents. About 15.8% of respondents in Mokowe were of Somali origin, while 16.6% of respondents in Mkunumbi were Sanye.

Table 4: Ethnic communities in the study area

Ethnicity	**Proportion of responses (%)**				
	Manda Maweni (n=26)	**Matondoni (n=20)**	**Mea (n=18)**	**Mkunumbi (n=24)**	**Mokowe (n=22)**
Bajuni	7.2	95.0	30.4	75.0	57.9
Boni	3.6	0.0	0.0	0.0	5.3
Borana	0.0	0.0	13.0	0.0	0.0
Digo	0.0	0.0	4.3	0.0	0.0
Giriama	10.7	5.0	0.0	4.2	0.0
Gunya	0.0	0.0	0.0	0.0	5.3
Kamba	0.0	0.0	4.3	0.0	0.0
Kikuyu	17.9	0.0	43.5	0.0	5.3
Kisii	10.7	0.0	0.0	0.0	0.0

Ethnicity	Proportion of responses (%)				
	Manda Maweni (n=26)	Matondoni (n=20)	Mea (n=18)	Mkunumbi (n=24)	Mokowe (n=22)
Luhya	10.7	0.0	0.0	0.0	5.3
Luo	35.7	0.0	0.0	0.0	0.0
Orma	0.0	0.0	0.0	4.2	0.0
Sanye / Watha / Waata	0.0	0.0	4.3	16.6	0.0
Somali	3.6	0.0	0.0	0.0	15.8
Taita	0.0	0.0	0.0	0.0	5.3

The historical integration of immigrants into Lamu's social fabric, based on shared ideologies of respect and economic status, contrasts sharply with the attitudes and practices of contemporary newcomers - both Western expatriates and immigrants from Kenya’s mainland, who assert their separate ethnic and religious identities and reject assimilation into Lamu's social hierarchy. This shift is evident in their attire, interactions, and spatial claims within the town, with behaviours such as alcohol consumption, open mingling between genders, and settlement in previously marginalised areas challenging traditional norms and social structures (Hillewaert, 2019).

The literacy level on the Kenyan coast is low compared to other parts of the country, there exists a disparity in education level between males and females as well as urban and rural population (GoK, 2017). Data from the Census Report (2019) in Lamu West Sub-County, with a total population of 88,070, where the study site is located reveal that 57.82% of the population have reached primary school, 10.98% pre-primary, 22.85% secondary school, 4.91% TVET, 2.02% University level, 1.06% Madrasa, and 0.10% Adult basic education. The rest either did not know their education levels or did not state it. Table 5 below shows the proportion of respondents by highest level of education reached during the interviews. Most of the respondents in Mokowe either had dropped out of school at primary level (21.10%) or had attained secondary level education. Most of the respondents at Mkunumbi were primary school dropouts (37.5%) or had attained primary level education (29.2%). Most of the respondents at Mea (30.4%) had had no formal education. Most of the respondents at

Matondoni had attained primary level education (30.0%), while most of the respondents at Manda Maweni were either primary school dropouts (28.6%) or had attained secondary level education (28.6%). The least proportion of respondents to have attained College/University level education were at Mkunumbi (0.00%) and Mea (4.3%).

Table 5: Highest education level attained by respondents in the villages surveyed

Education level	**Proportion of respondents (%)**				
	Manda Maweni (n=26)	**Matondoni (n=20)**	**Mea (n=18)**	**Mkunumbi (n=24)**	**Mokowe (n=22)**
None	3.6	20.0	30.4	16.7	10.5
Primary dropout	28.6	15.0	26.1	37.5	21.1
Primary	17.9	30.0	8.7	29.2	15.8
Secondary dropout	14.3	10.0	8.7	0.0	0.0
Secondary	28.6	5.0	21.7	16.7	21.1
College/ University	7.1	20.0	4.3	0.0	31.6

4.6 Livelihood Options

Lamu County's economy is diverse, with several sectors supporting the livelihoods of its residents. The primary economic activities in Lamu include tourism, which accounts for 45%, followed by ports and shipping at 15%. Agricultural industries and small-scale businesses contribute 8%, fisheries 6%, farming 5%, forestry 4%, mining 2%, and other services 15% (GoK, 2009). Men typically engage in fishing, small-scale farming, and mangrove cutting, while women participate in small-scale businesses, making palm thatch, and producing household wares (GoK, 2017). These activities are closely linked to the county's rich biodiversity and are strengthened by inter-community interactions through trade, religious practices, and cultural exchanges (Lamu County Government, 2018). Despite the availability of resources, Lamu remains one of the poorest counties in Kenya, with many residents relying on subsistence-level economic activities.

Agricultural productivity in Lamu varies depending on soil types. In Amu, for example, the red loamy soil supports the cultivation of food and cash crops such as maize, beans, cassava, and cowpeas, while sandy soils sustain coconut palms and cassava (Lamu County Government, 2018). Communities on Amu Island, the largest of Lamu's 65 islands, are engaged in trading, farming, and fishing, with their practices influenced by cultural and spiritual traditions.

Tourism plays a crucial role in Lamu's economy, particularly in Shella village, which is located about 3.2 km south of Lamu Old Town. Known for its spectacular beaches and its connection to Old Town via a coastal footpath, Shella attracts many tourists. Additionally, farming is practised in the area, although tourism remains the dominant economic activity (Lamu CSP 2016-2026). Similarly, fishing is a vital livelihood in Lamu, including Mkunumbi, where the sheltered creeks support prawn fishing, bolstered by the local mangrove ecosystem. Mangrove forests are essential to Lamu's economy, providing raw materials for construction, fuel, and tools used in fishing. Additionally, mangroves contribute to coastal protection, carbon sequestration, and habitat provision for marine life, making them invaluable for both economic and environmental sustainability (Lamu CIDP 2018-2022). A recent study revealed that fishing and farming were the main sources of livelihood constituting 65% of responses. Other important livelihood activities included boat operators, small-scale businesses, livestock keeping, bee keeping, mangrove cutting, politician/community leaders, professional or semi-skilled (Kamau & Maritim, 2024).

Household surveys from the present study indicate 13 primary livelihood activities are conducted in the study area (Table 6). In Manda Maweni, most of the respondents said that they conduct quarrying (25%), small-scale businesses (14.3%), crop farming (10.7%), and fishing (10.7%). Matondoni respondents reported that they largely engage in weaving (20%) and small-scale businesses, while most Mea respondents reported that they depend on crop farming (39.1%), fishing (17.4%), and small-scale businesses (13.0%) as their primary livelihood activity. In Mkunumbi, most of the respondents reported that they rely on firewood harvesting (29.2%) and fishing (25%) as their primary livelihood activity, while in Mokowe, respondents reported that, they largely dependent on fishing (26.3%), livestock farming (10.5%), and food vending (10.5%) as their primary livelihood activity.

Despite the diversity of livelihood activities in the region, interviews revealed that unemployment remains a significant challenge, pointing to limited job opportunities. Household surveys indicate that unemployment is particularly high in Mokowe (21.1%), followed by Matondoni (20%), Manda Maweni (17.9%), and Mea (17.4%), with Mkunumbi having the lowest rate at 8.3%. These figures highlight the struggle many residents face in securing stable employment, even with the presence of economic activities such as fishing, farming, and small-scale businesses. Previous studies have found out that unemployment is a persistent concern, with even a higher proportion of residents reported (Maingey *et al.,* 2022) than those reported in this study to be unemployed in this area. The studies reveal that this impacts on the ability of residents to buy basic commodities underscoring the need for expanding economic opportunities and diversifying livelihood options to reduce the high levels of unemployment.

Table 6: Proportion of respondents (%) in relation to primary livelihoods

Primary livelihood activity	**Proportion Responses (%)**				
	Manda Maweni (n=26)	**Matondoni (n=20)**	**Mea (n=18)**	**Mkunumbi (n=24)**	**Mokowe (n=22)**
Boda Boda	0.0	0.0	0.0	4.2	0.0
Small-scale business	14.3	20.0	13.0	8.3	5.3
Crop farming	10.7	5.0	39.1	0.0	0.0
Employed	7.1	10.0	0.0	16.7	10.5
Fish trader	0.0	5.0	0.0	0.0	0.0
Fishing	10.7	15.0	17.4	25.0	26.3
Food vendor	0.0	0.0	0.0	4.2	10.5
Harvesting firewood	0.0	0.0	4.3	29.2	5.3
Livestock Farming	3.6	0.0	8.7	0.0	10.5
Masonry	7.1	5.0	0.0	4.2	0.0
Mechanic	3.6	0.0	0.0	0.0	5.3
Quarrying	25.0	0.0	0.0	0.0	0.0
Retired	0.0	0.0	0.0	0.0	5.3
Unemployed	17.9	20.0	17.4	8.3	21.1
Weaving	0.0	20.0	0.0	0.0	0.0

4.7 Asset Ownership

Census data on the percentage distribution of conventional households by ownership of selected assets in Lamu West Sub-County shows varying levels of asset possession (Census 2019). Specifically, 38.9% of residents own a standalone radio, 32.1% own a bicycle, 31.1% own a functional television, 17.2% own a motorcycle, and 12.8% have internet connectivity. Additionally, 8.4% of households own a refrigerator, 4.5% own a desktop computer, laptop, or tablet, 3.8% possess an analogue television, 1.5% own a car, and 0.5% own a truck, lorry, bus, three-wheeler truck, or tuk-tuk.

Census data from 2019 also reveals that the main type of cooking fuel used in Lamu West Sub-County is predominantly firewood, utilised by 58.3% of households, followed by charcoal at 28.8%, and gas at 9.8%. Other cooking fuels include paraffin (1.7%), electricity (0.6%), biogas (0.5%), and solar (0.3%). In terms of lighting fuel, 40.7% of residents use mains electricity, 28.5% use solar energy, and 9.0% rely on torches or spotlights powered by dry cells. Other lighting sources include paraffin tin lamps (7.8%), solar-charged torches or spotlights (6.4%), paraffin lanterns (3.9%), wood (1.5%), candles (1.5%), and less common sources such as paraffin pressure lamps, car batteries, generators, or gas lamps (all below 0.2%).

Household surveys further revealed asset ownership patterns across villages in Lamu West Sub-County. Electric refrigerators, gas stoves, indoor piped water, livestock (chickens, goats, cows), non-smartphones, outdoor wells, pit latrines, private toilets, donkeys, radios/cassette/CD players, smartphones, televisions, and wood stoves are owned by at least one household in each village (Table 7). In Manda Maweni, the most commonly owned items are wood stoves (12.2%) and smartphones (10.0%). In Matondoni, wood stoves (10.7%) and televisions (10.7%) are the most frequently owned items. In Mea, pit latrines (12.9%), wood stoves (11.9%), and chickens (10.9%) are the most common. In Mkunumbi, wood stoves (19.6%), non-smartphones (13.0%), and chickens (7.6%) dominate household assets. Finally, in Mokowe, the highest proportion of households own televisions (11.4%), smartphones (10.5%), gas stoves (9.6%), and wood stoves (8.8%).

Table 7: Percentage distribution of respondent households by ownership of selected household assets. Proportions in a site add up to 100%.

Household items	**Proportion of responses in each site (%)**				
	Manda Maweni (n=26)	**Matondoni (n=20)**	**Mea (n=18)**	**Mkunumbi (n=24)**	**Mokowe (n=22)**
Computer	2.8	0.0	0.0	0.0	0.9
DVD/VCD player	3.9	2.5	0.0	0.0	1.8
Electric refrigerator	1.1	1.6	1.0	4.4	4.4
Freezer	0.0	0.8	0.0	0.0	0.0
Gas stove	4.4	5.7	3.0	4.3	9.6
Indoor water pipe	2.2	3.3	2.0	3.3	1.8
Chicken	11.1	1.6	10.9	7.6	6.1
Water pump	0.0	0.0	0.0	0.0	0.9
Goat	6.7	0.8	6.9	4.3	1.8
Cow	1.7	0.8	6.9	1.1	0.9
Non-smart phone	5.6	9.8	8.9	13.0	7.0
Outdoor well	1.1	8.2	9.9	2.2	3.5
Pit latrine	6.1	9.0	12.9	8.7	7.9
Private toilet	5.6	9.0	4.0	8.7	7.9
Donkey	3.3	3.3	1.0	1.1	1.8
Radio/casset/CD	4.4	1.6	2.0	1.1	1.8
Satellite dish	3.3	7.4	0.0	5.4	5.3
Second house	1.7	1.6	5.0	0.0	0.9
Septic system	1.7	0.0	1.0	1.1	4.4
Smartphone	10.0	9.0	5.0	6.5	10.5
Stereo	1.7	2.5	0.0	0.0	0.9
TV	7.8	10.7	7.9	7.6	11.4
VCR	1.7	0.0	0.0	0.0	0.0
Wood stove	12.2	10.7	11.9	19.6	8.8

Moreover, the results from the household survey indicate that household ownership, in terms of wall, roof, floor types, and lighting, varied among the villages. In terms of walls, mud walls were the most common in Manda Maweni (36.4%), Mea (55.0%), Mkunumbi (54.2%), and Mokowe (37.5%), while in Matondoni, most houses had stone walls (80.0%). Grid electricity was the most common source of lighting in Matondoni (85%), Mkunumbi

(54.5%), and Mokowe (61.1%), whereas solar power was predominantly used in Manda Maweni (80%). Concrete was the most common floor type in Manda Maweni (53.3%) and Matondoni (90%), while dirt floors were more common in Mea (72.2%), Mkunumbi (68.2%), and Mokowe (42.1%). Thatch roofing was widespread in Manda Maweni (72.4%) and Matondoni (80.0%), metal roofing was more common in Mea (66.7%), and concrete slab roofing was the most common in Mokowe (45.0%) (Figure 5).

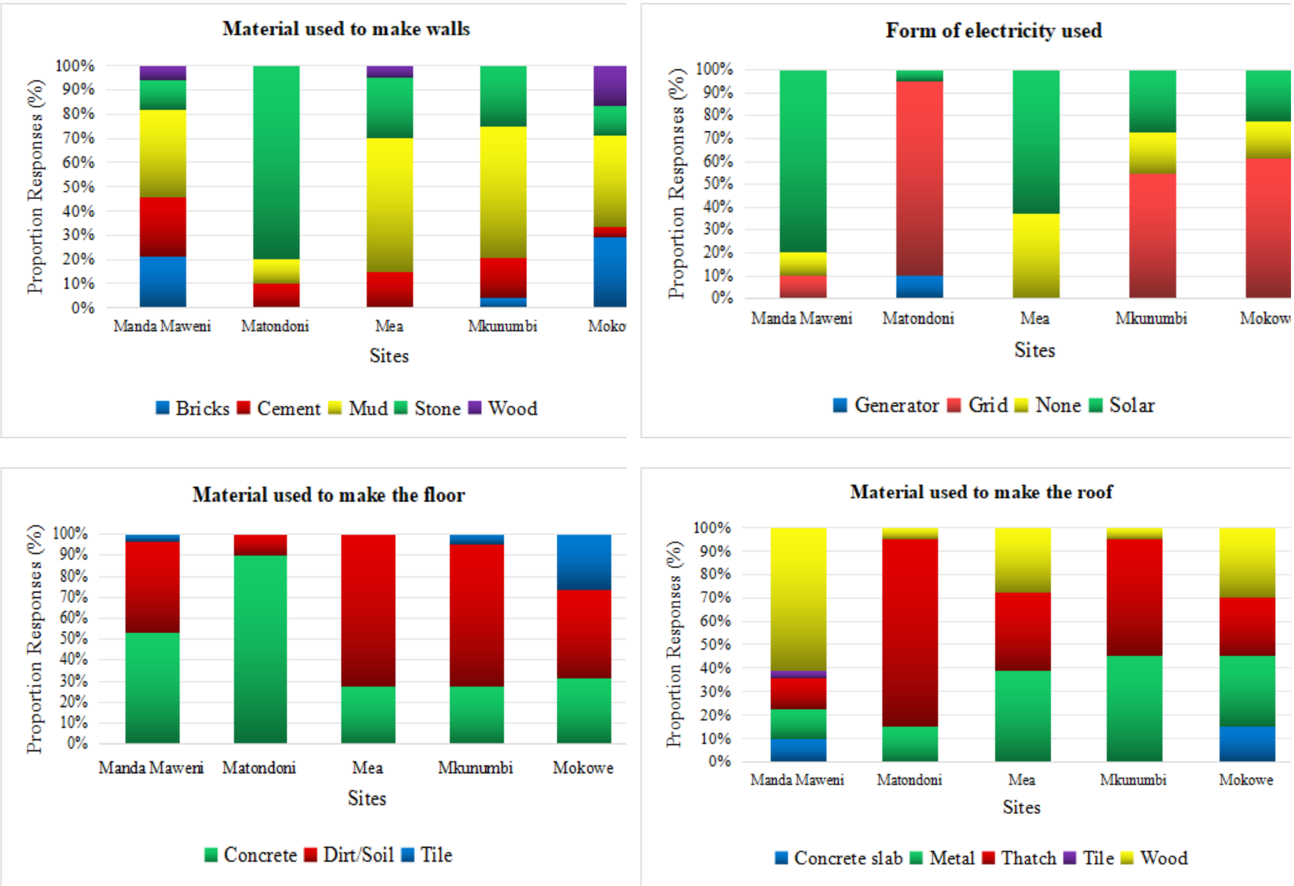


Figure 5: Percentage distribution of material style of life items per site. Proportions in a site for each category add up to 100%.

Chapter 5: Environmental Variables as Key to Understanding Ecosystem Functioning

5.1 Physico-chemical Parameters

Mangrove ecosystems are adapted to various environmental settings characterised by stress gradients associated with interactions among nutrients and soil salinity in addition to frequency, duration, and depth of flooding (Twilley & Rivera-Monroy, 2005). Salinity influences the health, distribution, growth and productivity of mangroves (Ball, 2002). It shows spatiotemporal fluctuations arising from tidal inundation, proximity to the shoreline, and water flow patterns (Van Tang *et al.,* 2020). According to Ball (1988), the optimum salinity for mangrove growth ranges from 5 to 50% seawater. Patel *et al.* (2010) reported optimal mangrove growth within a salinity range of 5-20 ppt with a decline observed as salinity increases.

Mangrove ecosystems experience low pH from high bacterial respiration rates, high polyphenolic acid concentrations, and metabolic processes in mangrove trees and roots (Holguin *et al.,* 2001). pH values ranging from 6 to 8 favor microbial respiration and activity (Zhou *et al.,* 2011) which in turn enhances biogeochemical cycles such as carbon cycling, nitrification, denitrification, and phosphate solubilization in the mangroves (Liu & Lai, 2019). Additionally, mangroves absorb atmospheric CO_2 and store it as organic carbon in sediments, with the carbon storage capacity greatly influenced by sediment grain size (Ray et al., 2018; Asante *et al.,* 2024).

Nitrates and phosphates are essential for mangrove growth, with their availability being influenced by factors such as soil composition, tidal patterns, nutrient inputs, and microbial activity (Reef *et al.,* 2010)). Mangrove ecosystems naturally eliminate or reduce nitrogen pollution through ammonia adsorption, resulting in ammonia being trapped in sediment (Vymazal, 2022). Studies have shown that pH influences the conversion of ammonia into nitrate (via nitrification) by shaping the distribution and population of ammonia-oxidizing archaea and bacteria (Zhao *et al.,* 2020). While mangroves can function as nutrient sinks, nutrient enrichment results in algal blooms (Paerl, 1997), reduced biodiversity and ecosystem resilience (Scheffer *et al.,* 2001), and the formation of dead zones (Rabalais *et al.,* 2002).

5.2 Hydrology and Ecosystem Dynamics of the Site

Mangrove hydrology is made up of three components, namely hydroperiod (frequency of inundation), hydrodynamics (what happens to the fluid in motion), and freshwater input from rainfall, rivers, or groundwater flows. Alongi & Brinkman (2011) revealed that mangrove hydrology is an important factor particularly in defining the structure and functioning of any mangrove ecosystem. The conditions created by hydroperiod are responsible for the unique physical and chemical conditions of mangroves that influence several factors including soil anaerobiosis, organic matter accumulation, species richness, and species composition as well as primary productivity.

Moreover, the degradation of a mangrove ecosystem in most cases arises from the partial or total interruption of the hydrological dynamics of an area driven by natural or anthropogenic disturbances that interfere with the hydroperiod. The mangroves of the Southern Swamp are characterised by inundation classes shown in Table 8, mainly occurring in combinations of three to four classes based on tidal regime, elevation, and flooding frequency. This defines the species composition of the mangroves and to a small extent other structural attributes.

Table 8: Inundation classes of mangrove tree species of the Southern swamp

Inundation class	**Flooded by**	**Number of times flooded per month**	**Elevation (cm + MSL[1])**	**Elevation of inundation (minutes per day)**	**Species suitability (some species fall in multiple zones and therefore inundation classes)**
1	All tides	56-62	<0	>800	No species present on the seaward edge
2	Medium high tides	45-59	0-50	400-800	Large *A. marina* and *S. alba*
3	Normal high tides	20-45	50-100	250-400	*R. mucronate* and *B. gymnorhiza*
4	Spring high tides	2-20	100-150	150-250	*R. mucronata, B. gymnorhiza,* and *C. tagal*
5	Abnormal or equinoctial tides	0-2	150-210	10-150	*C. tagal, H. littoralis, A. marina* and *L. racemosa*

There are no permanent rivers draining into mangroves in Lamu, however, the freshwater supply is by seasonal streams and groundwater aquifers (County Government of Lamu, 2018).

[1] MSL - Mean Sea Level

The mangroves of the Southern Swamp are drained by the Mkanda, Bandari Salama, Mto wa Mkunumbi, and Hidio Creeks with other, smaller channels including Mto wa Kiongwe/Kimbo, Mawambwe, and Daimboi (Fig. 5).

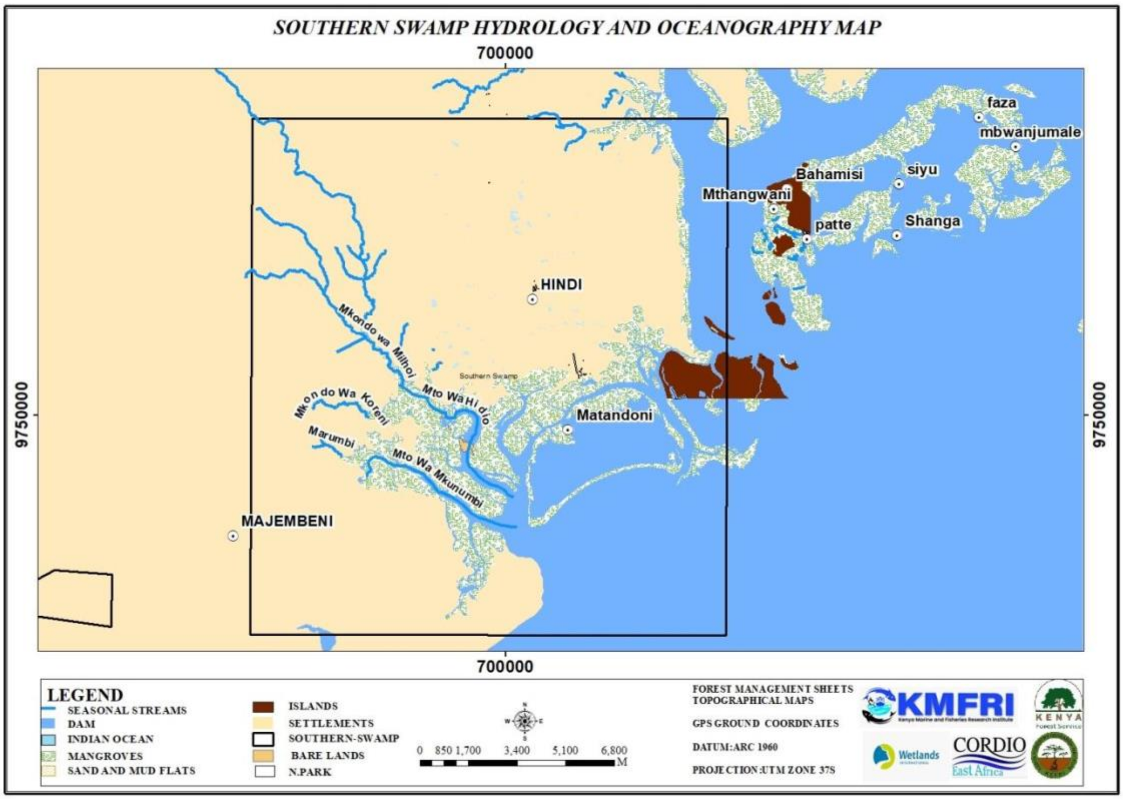


Figure 6: Map of the Southern Swamp hydrology and oceanography

5.3 Materials and Methods

The study sites were classified based on forest status (degraded and less disturbed) and tidal zones (landward and seaward). Degraded mangrove areas included Manda Island* and Kililana whereas less disturbed areas comprised Mkunumbi and Matondoni. The less disturbed areas were further clustered as either landward (D3 and D4) or seaward zones (A1, B2, D1, and D2) based on where the mangroves occurred in relation to tidal influence, refer to Figure 14. Further, channels within the mangrove areas which fill during flooding and are partially emptied during ebbing tides were considered for the collection of water samples.

The sampling design was structured to assess local variations in environmental variables across the inundation classes and disturbances levels. This approach aimed to correlate the data with findings from benthic and eDNA analysis. Measurement and analysis of water parameters was done at predetermined sampling substations where eDNA samples were also collected. Physicochemical parameters, including pH, total dissolved solids (TDS), salinity, dissolved oxygen (DO), temperature, oxidation-reduction potential, and conductivity were measured in situ by immersing a YSI multi-parameter probe in water. Additionally, surface water was collected in triplicates using a pre-cleaned plastic container and stored in 50 ml Eppendorf tubes before being transported to the laboratory for nutrient and turbidity analyses.

Three replicate sediment samples were collected using a 3.6 cm diameter corer up to a depth of 25cm, concurrently with benthic sampling, within plots of 20 by 20 m in designated transects laid in the areas described in paragraph 1 above. The samples were placed in well-labelled ziplock bags and transported to the laboratory for nutrient, organic carbon, and grain size distribution analyses.

5.4 Findings

The pH values obtained ranged from 6.25 to 7.01 with sites located on the landward zone recording a mean pH of 6.82±0.07 whereas those on the seaward zone had a mean of 6.86±0.06, indicating minimal variation (Figure 7). The degraded sites, however, had significantly lower pH values (6.42±0.17) as compared to the less disturbed sites (6.84±0.04). Lim et al. (2012) reported maximal mangrove seedling and tree growth at a pH range of 5.16 - 7.72 beyond which nutrients become unavailable to plants.

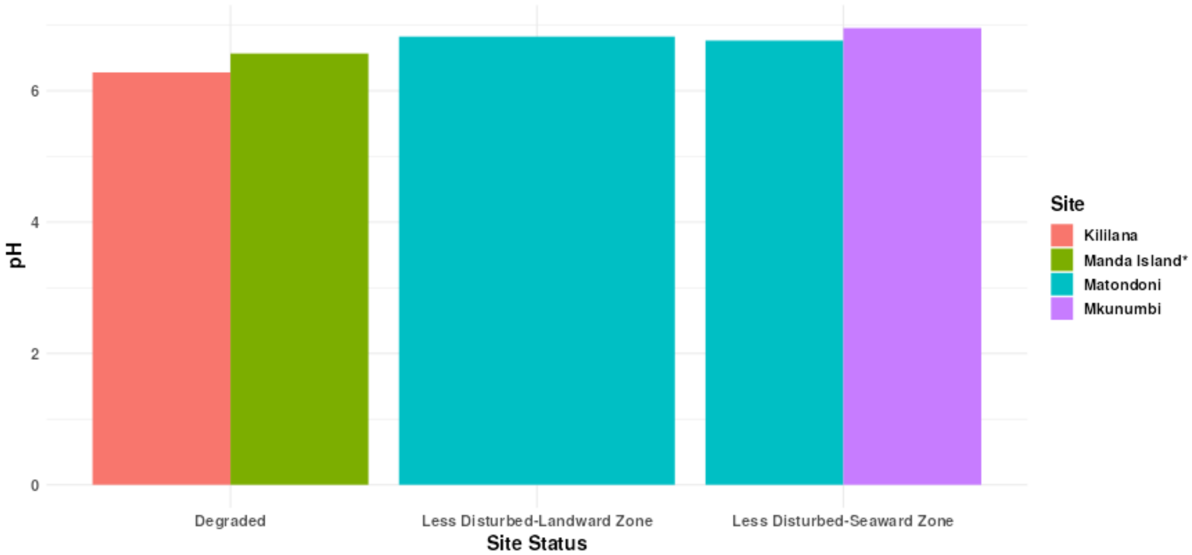


Figure 7: Mean pH values obtained from the sampling sites within the Southern Swamp mangroves

Salinity ranged from 33.69 to 49.20 ppt with higher values observed in degraded sites (42.18±6.40 ppt) as compared to the less disturbed sites (36.20±0.58 ppt), see Figure 8. Additionally, the landward zone recorded higher salinity (37.39±1.19 ppt) than the seaward zone (35.61±0.50). Krauss *et al.* (2008) reported that mangroves can grow and function up to a salinity of 90 ppt, however, optimal growth occurs when salinity varies from 5 to 75 ppt.

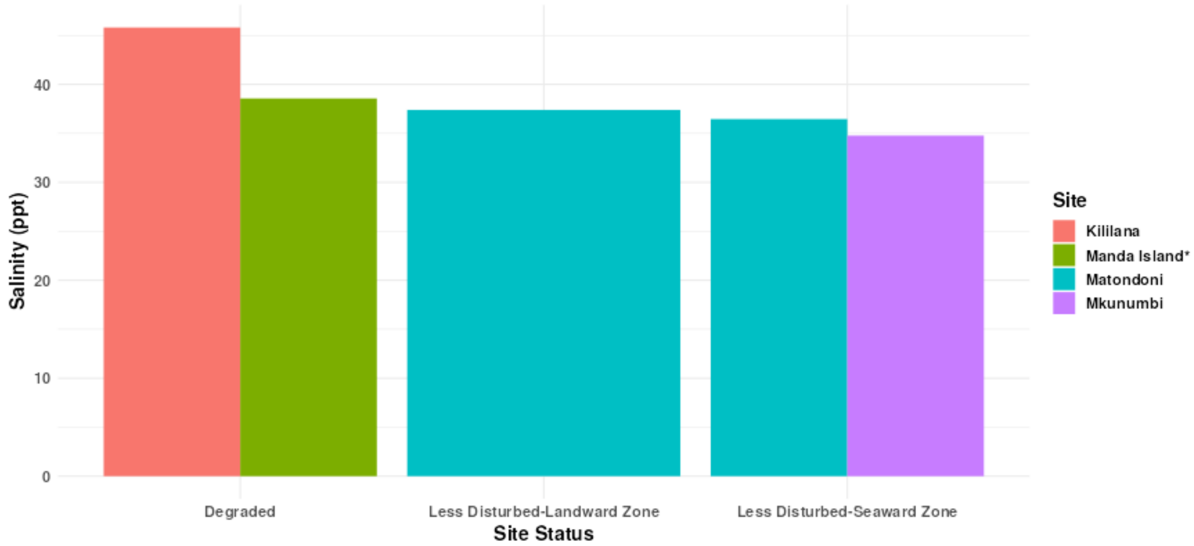


Figure 8: Average salinity values obtained from sampling sites within the mangroves of the Southern Swamp

The organic carbon (OC) content in the study area ranged from 3.02 to 27.28% with less disturbed sites recording a higher OC content (12.97±3.39%) than degraded sites (8.15±6.06%), see Figure 9. Similarly, the seaward zone had a higher OC content (14.69±9.50%) compared to the landward zone (9.51±6.12%).

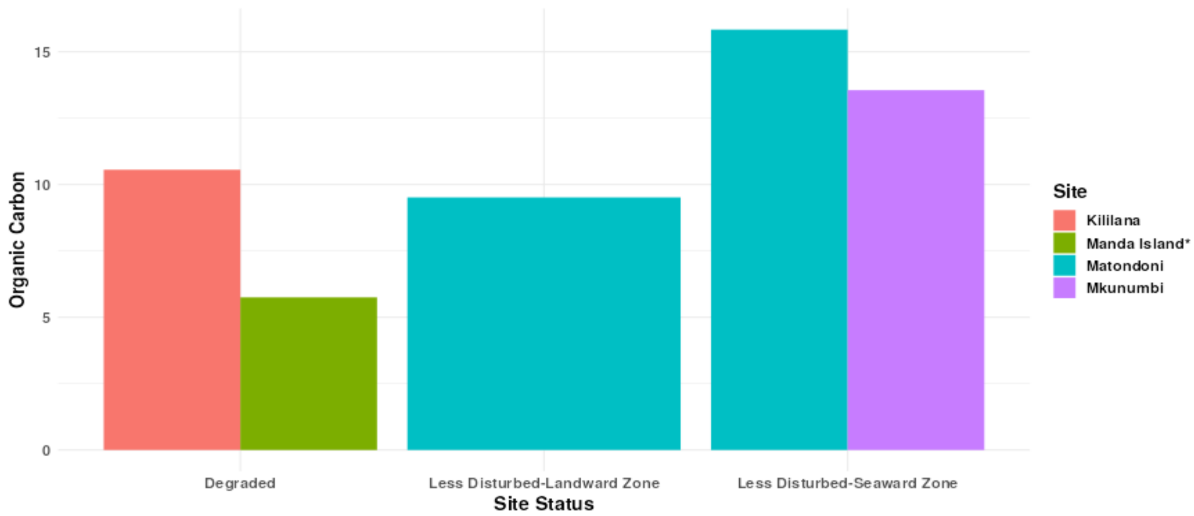


Figure 9: Mean organic carbon values from study sites within the mangroves of the Southern Swamp

The concentrations of nitrate and ammonia ranged from 0.86 to 8.93 mg/L, 0.06 to 0.43 mg/L, respectively (Fig. 9). Nitrate (NO_3^-) and ammonia (NH_3) concentrations were higher in degraded sites (NO_3^- - 7.49±0.98 mg/L; NH_3 - 0.19±0.17 mg/L) than in less disturbed sites (NO_3^- - 5.54±0.96 mg/L; NH_3 - 0.14±0.02 mg/L). The nitrate concentration recorded in the seaward zone (5.26±2.94 mg/L) was relatively lower than in the landward zone (6.11±1.01 mg/L). Similarly, ammonia concentrations were lower in the seaward zone (0.11±0.01 mg/L) as opposed to the landward zone (0.20±0.01 mg/L), see Figure 11.

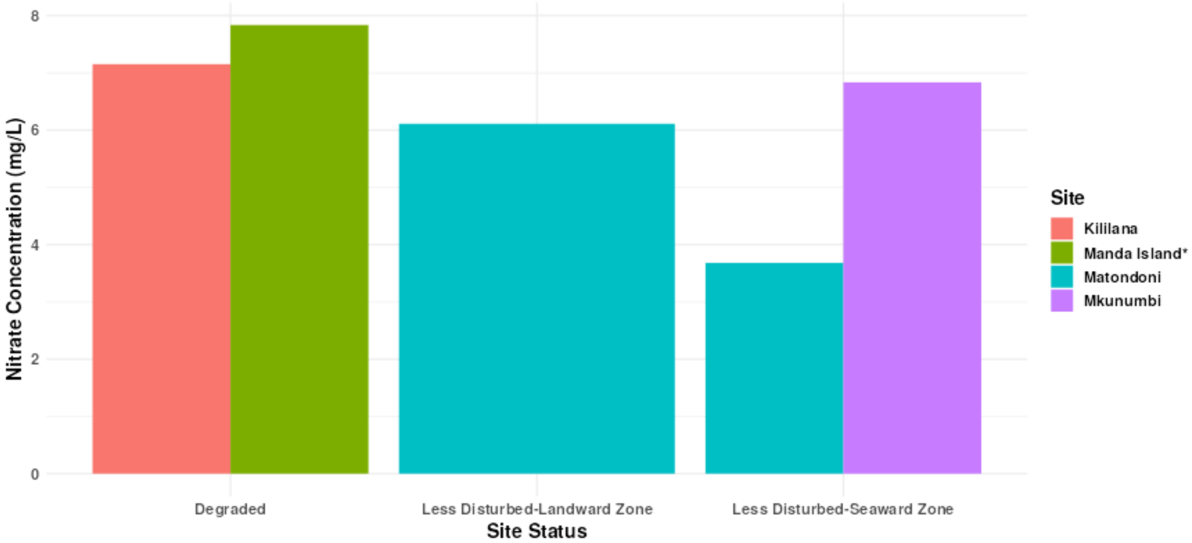


Figure 10: Average nitrate concentration in sampling sites within the Southern Swamp mangroves

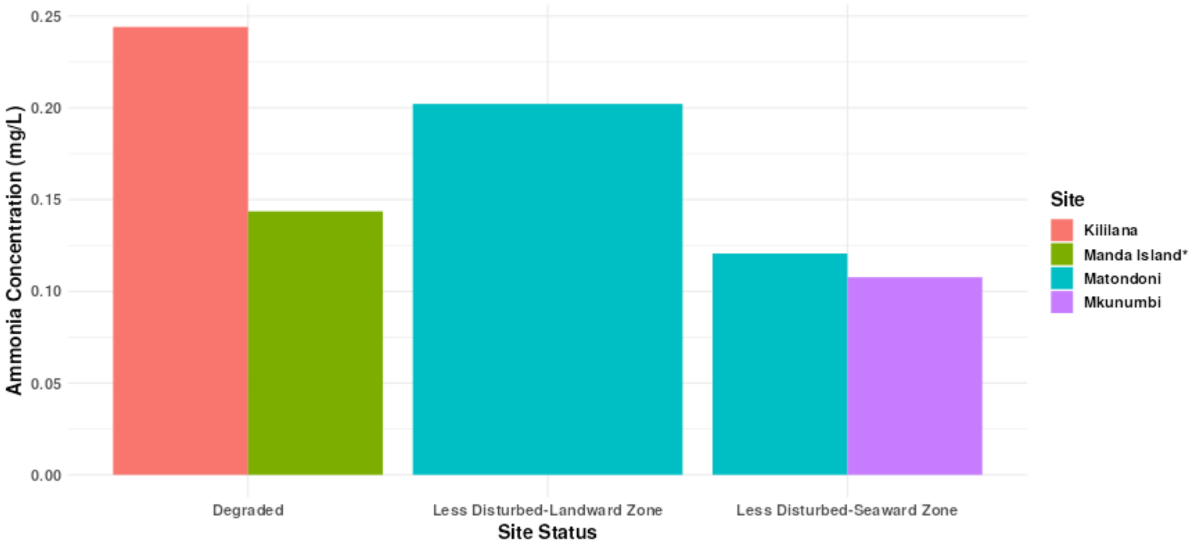


Figure 11: Mean ammonia concentration in sampling sites within the mangroves of the Southern Swamp

The concentration of phosphate within the study area ranged from 0.32 to 1.19 mg/L. Phosphate (PO_4^-) concentration in degraded sites (0.52±0.07 mg/L) and less disturbed sites (0.59±0.13 mg/L) was comparable (Fig. 11). However, the landward zone (0.81±0.54 mg/L) recorded a relatively higher phosphate concentration than the seaward zone (0.48±0.16 mg/L).

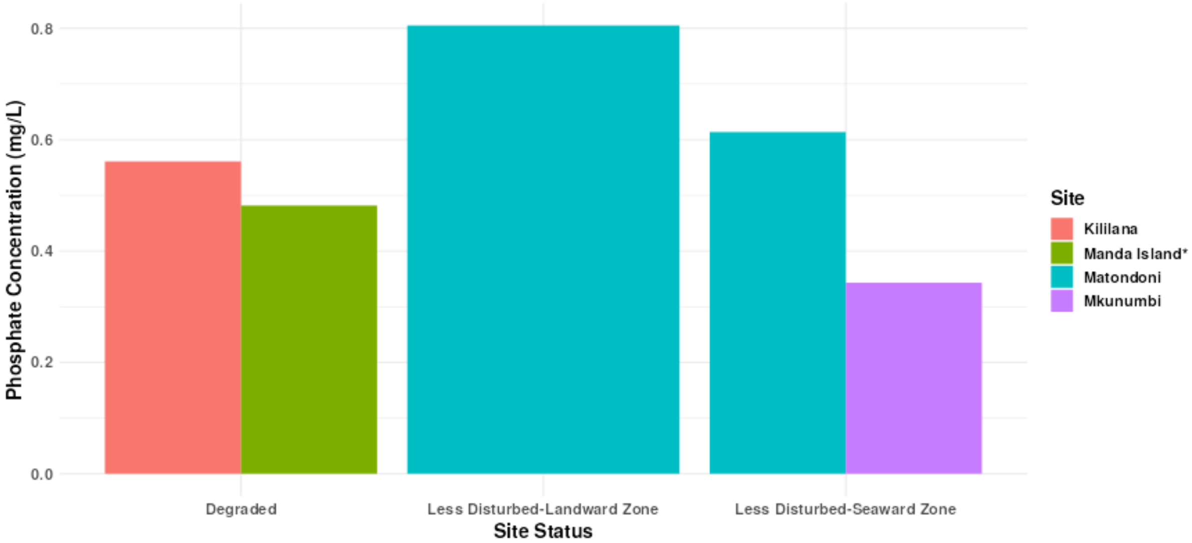


Figure 12: Mean phosphate concentration in sampling sites within the mangroves of the Southern Swamp

The composition of sediment grain sizes in the study site is given in Figure 13. There was a significantly higher composition of fine sand (68.41±6.53%) followed by very fine sand (11.16±2.32%), very coarse silt (6.22±1.55%), very fine silt (5.74±1.30%), clay (4.31±1.81%), and medium sand (2.83±0.60%) in that order. Degraded sites recorded significantly higher fractions of fine sand (82.26±6.32%) compared to the less disturbed areas i.e. the landward and seaward zones (59.17±9.02%). Additionally, the very fine silt fraction was higher in less disturbed sites (6.91%) than in degraded sites (3.99%).

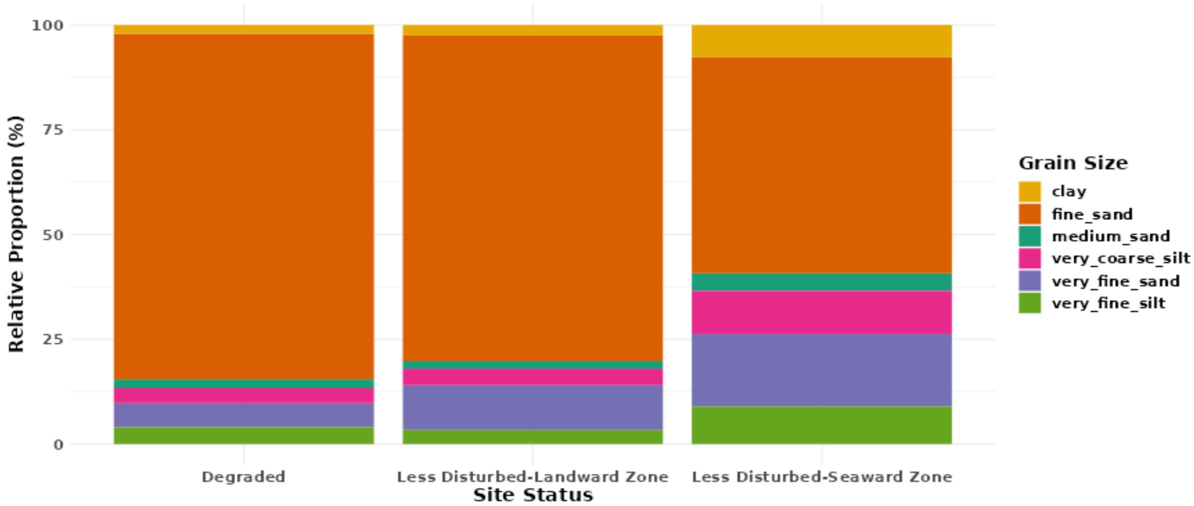


Figure 13: Distribution of grain sizes of sediment from the mangroves of the Southern Swamp

Chapter 6: Biodiversity of the Lamu Southern Swamp

6.1 Introduction

Mangroves are confined to the tropical and subtropical shorelines at the terrestrial-marine interface (Kamal *et al.*, 2014). These ecosystems are defined by salt-tolerant trees, shrubs, and a wide array of unique, endemic species that have evolved to flourish in fluctuating abiotic conditions such as variable salinity, temperature, waterlogging, and tidal changes (Rastogi *et al.*, 2021). Being a biodiversity hotspot zone, mangroves host unique birds, fish, mammals, plants, and microbial species with significant contributions to the socio-cultural and economic well-being of over 4.3 million coastal inhabitants in Kenya (GoK, 2017; KNBS, 2019). Moreover, the ecosystem plays a role in protecting the coast from the vagaries of nature, mitigating climate change through carbon sequestration, and providing nursery grounds for different fish and other wildlife.

The mangroves of Lamu stand out for their biodiversity rich and relatively intact forests. Notably, much of Lamu's mangrove-associated biodiversity remains under-documented, with available data being limited and fragmented. The lack of comprehensive biodiversity information hampers the development of an integrated approach for effective conservation and management of Lamu mangrove ecosystems. This assessment incorporated three approaches: (1) a review of literature to gather existing documented taxa, (2) classical field surveys to evaluate forest structure and associated avifauna diversity, and (3) the use of environmental DNA (eDNA) to detect a broad spectrum of species life domains. This combined methodology allows for a more holistic understanding of biodiversity, delivering valuable insights to guide conservation and management strategies for the Lamu Southern Swamp mangroves.

6.2 Secondary Data Collation

The collation of secondary data on mangrove biodiversity is essential for establishing baseline biodiversity metrics, which serve as critical references for conservation efforts and ecological assessments. Mangroves, known for their rich biodiversity and vital ecosystem services, face increasing threats from anthropogenic activities and climate change. By compiling existing data from various studies, surveys, and monitoring programs, researchers can create a comprehensive overview of species composition, distribution and ecological functions within the mangrove ecosystem. This baseline data is crucial for understanding the current state of biodiversity, assessing changes over time, and evaluating the impact of environmental stressors.

Furthermore, establishing a robust baseline allows for the effective application of the mitigation hierarchy in biodiversity management, enabling stakeholders to make informed decisions regarding conservation strategies. It facilitates the identification of key species and habitats that require protection and restoration efforts. Additionally, baseline data supports the development of biodiversity offset schemes aimed at achieving no net loss of biodiversity in areas impacted by development projects. Ultimately, secondary data collation not only enhances our understanding of mangrove ecosystems but also informs policy-making and management practices that are vital for the sustainability of these critical habitats.

In this study, a structured search of online databases for relevant articles documenting biodiversity and related information of Lamu Southern Swamp mangrove forest was conducted between January 10th and May 15th, 2024. The search was restricted to documents published between 1960 and 2023. The identified documents were filtered and only those with comprehensive taxa list were retained for species name retrieval.

6.2.1 Results from Existing Literature

Five (5) documents out of the 76 publications were found to have biodiversity information specific to coastal forests in Lamu, though none had taxa lists specifically from Lamu Southern Swamp Mangrove Forest. A total of 186 identified species were obtained from the 3 peer-reviewed articles, while 142 were listed in 2 grey literature. Terrestrial forests accounted for 92.99% (n = 305) of the total documented species in the study. In contrast, only 23 species were recorded from the mangrove forests of Lamu, Kiunga, and Pate Island. Majority of the documented taxa belonged to the Kingdom Animalia (n = 295), while the Kingdom Plantae was represented by only 33 species. Among the animal taxa, Aves had the highest representation, with 191 species recorded, followed by mammals (n = 52), Magnoliopsida (n = 33), Squamata (n = 29), and amphibians (n = 13). The least represented classes were Trematoda and Insecta, each with only one species documented in the records. This disparity highlights the significant biodiversity present in terrestrial ecosystems compared to mangrove habitats in this region, emphasising the need for further research and conservation efforts focused on enhancing our understanding of mangrove biodiversity.

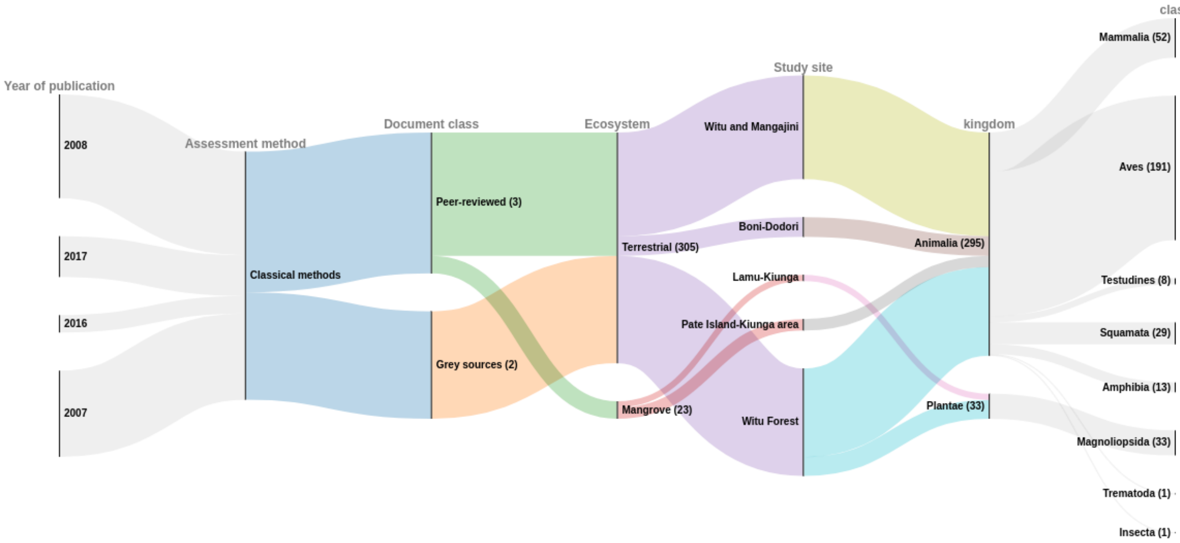


Figure 14: Sankey plot illustrating the review process and the information obtained

6.3 Primary Biodiversity Data Collection

The assessment of mangroves and the associated biodiversity, conducted through mangrove structural surveys, avifauna assessments, and eDNA analysis, revealed varying levels of species diversity, composition, and structure. Conventional biodiversity assessment (conducted in May 2024), which included forest structure surveys for mangroves, point count and line transect techniques for avifauna surveys, identified five (5) mangrove species and 86 bird species. In contrast, the eDNA analysis from samples collected during the same field campaign, identified a total of 7,999 unique taxa from both terrestrial and marine ecosystems.

6.3.1 Forest Structural Attributes

Forest structural surveys are conducted to infer forest health and establish merchantable wood volumes for sustainable forest management. Studies have, for instance, proven that there exist significant linkages between forest composition and soil characteristics hence influencing carbon emission and sequestration processes and climate change (Lovelock *et al.*, 2011; Donato *et al.*, 2011).

In this section of the study, at total of 21 plots of 20 m by 20 m were established and sampled within predetermined belt transects that reflect as good enough representation of the entire Lamu Southern swamp: 9 in Mkunumbi, 4 in Matondoni, 3 in Mokowe, 3 in Kililana, and 2 in Manda Island (Figure 15). Deliberate efforts were also made in setting up the sampling plots to ensure that all tidal flooding regimes (inundation classes) and degradation were captured. All sampling plots were georeferenced using a Garmin hand-held Global Positioning System (GPS) 76 receiver for future reference.

Within each plot, all mature trees with a diameter at breast height (DBH) ≥2.5 cm were counted and structural attributes including height (m), DBH (cm) measured, and species noted as described in Kairo (2001) and Okello et al., (2013). Additionally, natural regeneration was assessed and classified into respective regeneration classes based on a linear regeneration sampling protocol (FAO, 1994).

Figure 15: Map of Lamu Southern swamp situating transects laid for collection of structural attributes data and benthic community

From the field data, species composition, mean stem densities, tree heights, basal area, utilisation classes, and biomass carbon were computed to determine the ecosystem's resilience, biodiversity, healthy, maturity and growth condition, carbon sequestration potential, respectively. Stump densities were analyzed as an indicator of human-aided degradation, while natural regeneration was examined as a measure of natural recovery.

Findings

Floristic Composition

A total of 4 (Figure 16, Table 9) out of the possible 9 mangrove tree species documented in Kenya (Bosire *et al.*, 2016) were encountered in the study area (Figure 16). *R. mucronata* (153.83%) was the most dominant followed by *C. tagal* (116%), the two species accounting for >70% of the total forest formation. Other species included *Avicennia marina*, and

Bruguiera gymnorhiza, in that order of dominance (Table 9). *Lumnitzera racemosa, Sonneratia alba,* and *Xylocarpus granatum* were not encountered within the transects but were mentioned by the local guides as being present in the area. For example, *S. alba* is known to occur in Lamu Southern swamp (Kairo *et al.,* 2021) while *Heritiera litoralis* is known to occur in abundance just south of Lamu Southern swamp in Tana Delta (Samoilys*et al.,* 2011). Other species not observed or mentioned by local guides (viz. *H. littoralis, L. racemosa,* and *Xylocarpus moluccensis*) are relatively rare along the Western Indian Ocean in general (Bosire *et al.*, 2015) and their absence in the sampling pool does not completely rule out their occurrence in Lamu Southern swamps. The dominance of *R. mucronata* and *C. tagal* in the present study is similar to previous studies on mangroves in Kenya (e.g. Kairo *et al.,* 2002; Mohamed *et al.*, 2009, Mbatha *et al.*, 2023, Okello *et al.*, 2022 among others).

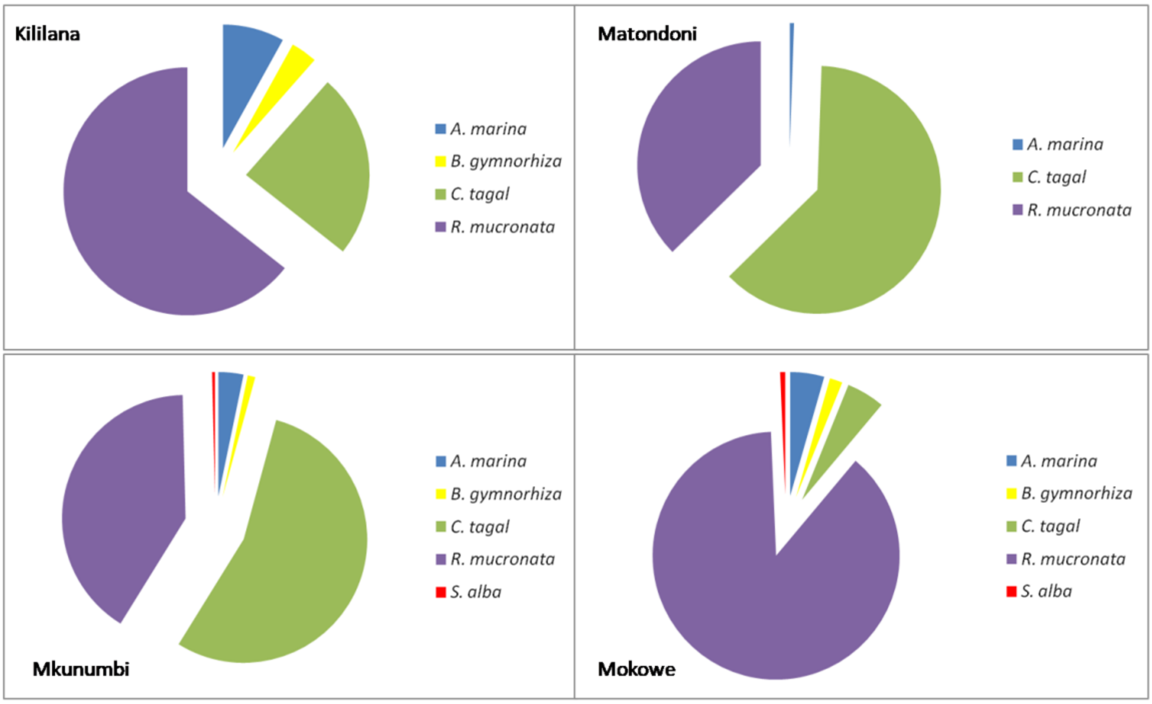


Figure 16: Mangrove tree species composition in the study sites within the Lamu Southern swamp. Manda Island* was a completely degraded site with no remnant mature trees

Table 9: Floristic composition and importance value of mangroves in Lamu Southern swamp

Species	Relative Values (%)			IV*(%)
	Dominance	**Density**	**Frequency**	
Rhizophora mucronata	67.58	46.25	40	**153.83**
Ceriops tagal	28.75	49.75	37.5	116
Avicennia marina	1.79	3.04	12.5	17.33
Bruguiera gymnorhiza	1.87	0.97	10	12.84
**Importance value (IV): Relative dominance+ Relative density+ Relative frequency The bold type represent the most important mangrove species in Lamu Southern swamp*				

Structural Attributes

The total stem densities varied across the sampling locations with highest values recorded at Matondoni (7,313±1834 stems ha^{-1}), while the lowest was at Kililana (725±588 stems ha^{-1}), and zero in Manda Island* sampling site which had no mature living trees. The mean stem density for the entire area was 2,936±1,408.08stems ha^{-1}. This value is significantly higher than stocking rates recorded in other mangrove areas along the Kenyan coast at Mida (Kairo *et al.*, 2002), Mombasa (Mohamed *et al.*, 2009), and Tana delta (Bundotich *et al.*, 2009) but slightly lower than 3,092 stems ha^{-1} reported by Kairo *et al.*, (2021) for the same swamp. In other mangrove swamps of Lamu, Okello *et al.*, (2022) reported 2,435.5 and 3171 stems ha^{-1} in Northern and Pate Island swamp, respectively. Across all the sites, 50% of the tree diameters and heights were between 3.48 – 8.9 cm and 2.5 – 6 m, respectively. The mean diameter of the trees ranged from 6.1 cm in Mkunumbi to 9.6 cm in Matondoni (mean: 6.3±1.7 cm) and height from 3.4 m in Kililana to 5.1 in Mokowe (mean: 3.3±0.9 m). Differences in mangrove tree diameters and heights is primarily attributed to both environmental and biological factors such as climate, topography, and the degree of human disturbance (Tomlison, 2016). Mangroves of Lamu Southern swamp have similar climate and topography, hence the differences in diameter and height observed in present study is mainly due to human disturbance. Other factors may include: species variation, soil conditions, age or succession stage, freshwater availability as well as hydrology and water flow. Similarly, natural disturbances like storms, erosion, or pests can affect mangrove growth patterns. Height-diameter scattergram of mangroves in Lamu Southern swamp is shown in Figure 17.

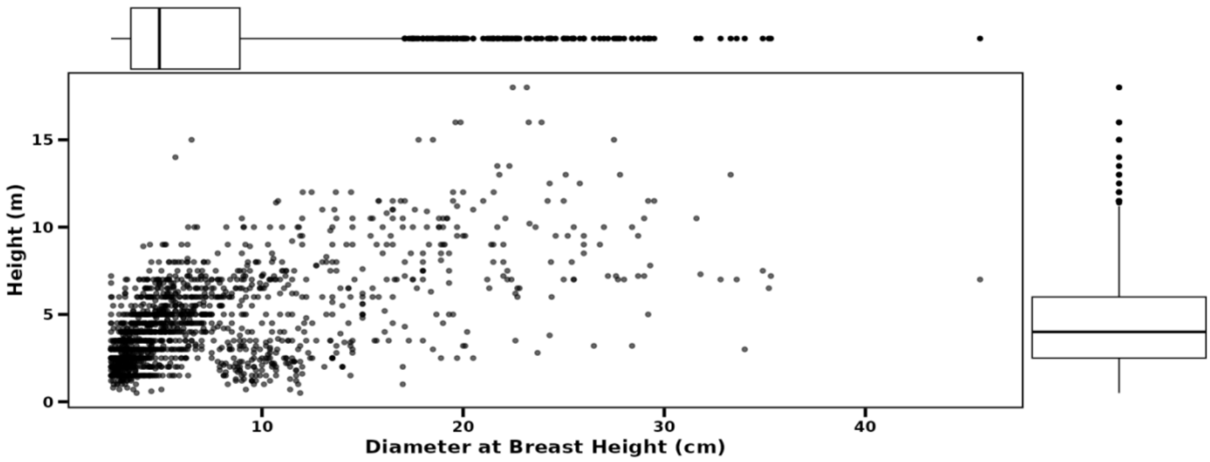


Figure 17: Height-diameter scattergram of mangroves in Southern swamp

Basal area (a cross-sectional area of tree trunks at breast height), is a reliable indicator of forest structure and biomass (Komiyama *et al.,* 2008). Mangroves of Lamu Southern swamp recorded a mean basal area of 28.67±17.10 m^2ha^{-1} (range:10.02 - 95.6 m^2ha^{-1}) which is higher than 21.69 m^2ha^{-1} recorded for the same swamp by Kairo *et al.,* (2021). Elsewhere in other swamps of Lamu, Okello *et al.,* (2022) reported slightly higher mean basal areas of 30.96 and 31.51 m^2ha^{-1} in Northern and Pate Island swamps, respectively. According to various mangrove studies, the BA of mangroves can vary significantly depending on their level of disturbance and age. Pristine, mature mangroves often have a BA > 20m^2ha^{-1}, while secondary and disturbed forests typically exhibit lower values (Alongi, 2009; Hutchinson *et al.,* 2014). Therefore, our mean BA of 95.6±48 m^2ha^{-1} in Matondoni indicates that the mangroves are pristine. The rest of the sites had mean basal areas < 20 m^2ha^{-1}, indicating the presence of disturbance to the forest or young secondary forest.

The standing biomass of mangroves in Lamu Southern swamp ranged from 107.82±106.83 to 1,023.3±531.2 Mg ha^{-1} (mean±SE: 300.48±184.17 Mg ha^{-1}) in Kililana. Together with the root biomass, the mean vegetation biomass was 421.94±255.90 Mg ha^{-1}. Matondoni and Kililana recorded the highest (1,426±737 Mg ha^{-1}) and lowest (150.57±149.04 Mg ha^{-1}) mean vegetation biomass (Table 10). Vegetation biomass 421.94±255.90 Mg ha^{-1} for the mangroves of Lamu Southern swamp is higher than 319.26 Mg ha^{-1} reported by Kairo *et al.,* (2021) for the same swamp. The mangroves in Lamu rank among the most productive ecosystems in Kenya (Kairo, 2001; Kairo *et al.,* 2002; Njiru *et al.,* 2022) and the wider Western Indian Ocean (WIO) region (Bosire *et al.,* 2012). This high productivity is linked to both geomorphic and oceanographic factors (Kairo, 2001; GoK, 2017; Njiru *et al.,* 2022). Despite the absence of permanent rivers draining into Lamu's mangroves, the East African

Coastal Currents may transport freshwater from the Tana River Delta northward to Lamu, enhancing marine productivity in the area (UNEP, 1998; ASCLAME, 2012; Kamau *et al.*, 2020). Additionally, the interaction between the southerly Somali Coastal Currents and the northward-flowing East African Coastal Currents could generate upwelling, further contributing to the region's high marine productivity (UNEP, 1998).

Table 10: Structural attributes of mangroves of Lamu Southern swamp, Lamu (mean±SE)

Site	Structural attributes						
	Mean DBH (cm)	**Mean Height (m)**	**Stem density (stems ha^{-1})**	**Basal area (m^2 ha^{-1})**	**Aboveground biomass (Mg ha^{-1})**	**Belowground biomass (Mg ha^{-1})**	**Total biomass (Mg ha^{-1})**
Mkunumbi	6.1±0.9	4.3±0.5	5,150±1,074	17.8±4.0	153.3±43.4	67.3±17.2	220.7±60.2
Matondoni	9.6±2.5	3.7±1.2	7,313±1,834	95.6±48	1,023.3±531.2	402.3±2005.6	1,426±737
Mokowe	9.1±2.3	5.1±1.6	1,492±648	19.9±10.3	218±115	87.7±44.8	304±159.3
Kililana	6.7±2.7	3.4±1.7	725±588	10.02±9.8	107.82±106.8	42.75±42.2	150.57±149.0
Manda Island*	00±00	00±00	00±00	00±00	00±00	00±00	00±00
All combined	**6.3±1.7**	**3.3±0.9**	**2,936±1,408.1**	**28.67±17.1**	**300.48±184.2**	**120.01±72.1**	**421.94±255.9**

Vegetation Carbon

Vegetation carbon stocks in mangroves of Lamu Southern swamp followed the order of the size of the mean diameter across the sites. The total vegetation carbon was estimated at 1,892,405.9 Mg C (mean: 196.9±120.2 Mg C ha^{-1}); with above-ground biomass carbon contributing 150.3±92.1 Mg C (or 76.3%) and belowground biomass carbon the rest (Table 11). Matondoni recorded the highest vegetation carbon (668.6±345.8 Mg C ha^{-1}), while Kililana registered the lowest values (70.58±69.88 Mg C ha^{-1}) – Table 11. When expressed in terms of CO_2 equivalent, the current vegetation carbon estimate of mangroves in Southern swamps translates to 722.623 Mg CO_2e ha^{-1}. Based on the current mangrove area in Lamu Southern swamp (9,611 ha), the amount of CO_2 equivalent in these mangroves as biomass is estimated at approximately 6.95 million Mg CO_2e (or 1.89 million Mg C).

Table 11: Contribution of different carbon pools to the total vegetation carbon of mangroves in Lamu Southern swamp, Lamu (mean±SE)

Site	Aboveground C stock (Mg C ha^{-1})	Belowground C stock (Mg C ha^{-1})	Total Biomass Carbon (Mg C ha^{-1})
Mkunumbi	76.7±21.5	26.3±6.7	102.9±28.2
Matondoni	511.7±265.6	156.9±80.2	668.6±345.8
Mokowe	109.2±57.2	33.4±17.5	142.6±74.7
Kililana	53.91±53.42	16.67±16.46	70.58±69.88
Manda Island*	00±00	00±00	00±00
All combined	150.3±92.1	46.5±28.1	196.9±120.2

Mangrove Exploitation

Evidence of selective harvesting, likely driven by market demand for straight poles, was observed across different utilization classes. This is highlighted by the notably higher stem densities of Fitos (2.5 – 6 cm butt diameter), compared to the lower densities in larger, more commercially valuable utilization classes (Figure 18). The disproportionate harvesting of larger trees suggests a preference for mature wood especially *Mazio* and *Boriti* (DBH range: 8 - 13.9 cm), while smaller stems remain more abundant. *Mazio* and *Boriti*-sized poles are the most preferred in building and construction industries in the region (Bosire *et al.*, 2016). Selective logging of mangroves in Kenya has been reported to contribute to low densities of merchantable wood products and reduction in forest quality over time (Kairo *et al.*, 2002; Mbatha *et al.*, 2022; Okello *et al.*, 2022).

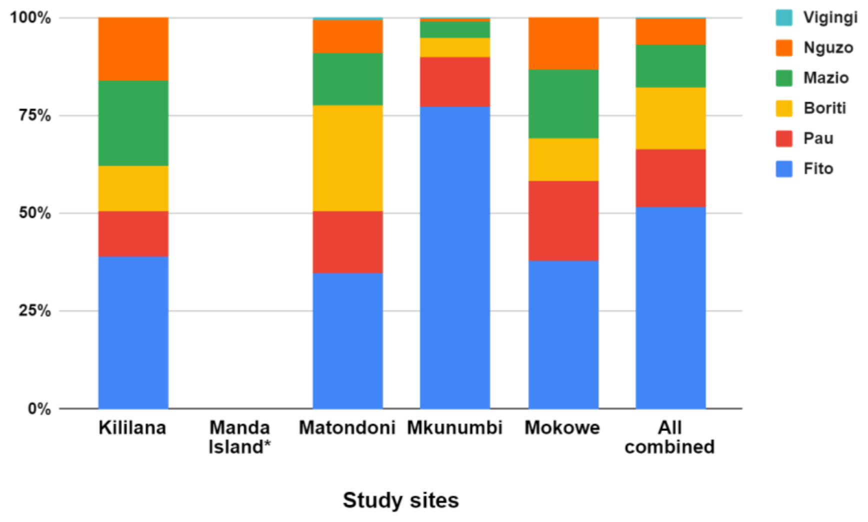


Figure 18: Proportion of mangrove utilisation categories per study site

The entire forest area was dominated by Form 3 poles (unsuitable for construction), with the highest proportion recorded in Matondoni (75.7%). Further, low densities of high-quality poles (Form 1) was also observed across the sites. In Mokowe, a significant density of stems were noted to be of Form 2 pole that require slight modification before use for construction.

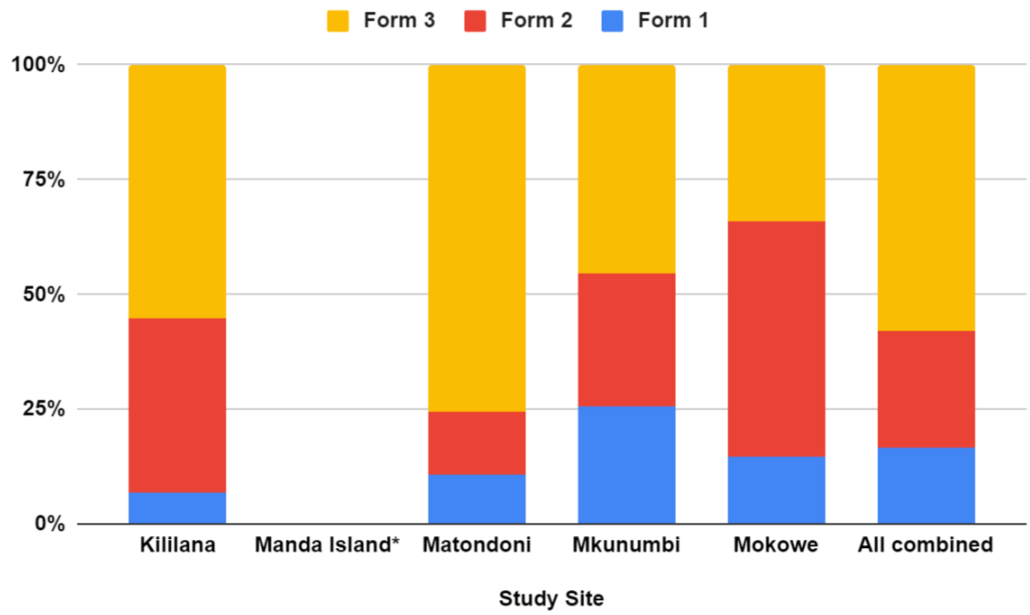


Figure 19: Proportion of mangrove stem quality classes in the study sites

The presence of stumps is a significant indicator of forest degradation resulting from anthropogenic activities (Mbatha *et al.*, 2023; Okello *et al.*, 2022). Kililana recorded the highest density of stumps (9,317±8,745 stumps ha^{-1}), while Matondoni recorded the lowest density (619±204 stumps ha^{-1}) (Figure 20). Most of the stumps belonged to *R. mucronata* followed by *C. tagal*, and most were *Boriti*-sized poles (DBH range: 11.5 - 13.9cm) and below.

In Kililana and Manda Island, the degradation of mangroves was primarily caused by encroachment and clear felling, leading to the significant loss of mangroves. In contrast, degradation in the rest of the sites was largely attributed to selective harvesting practices, which selectively remove certain tree sizes while allowing others to remain.

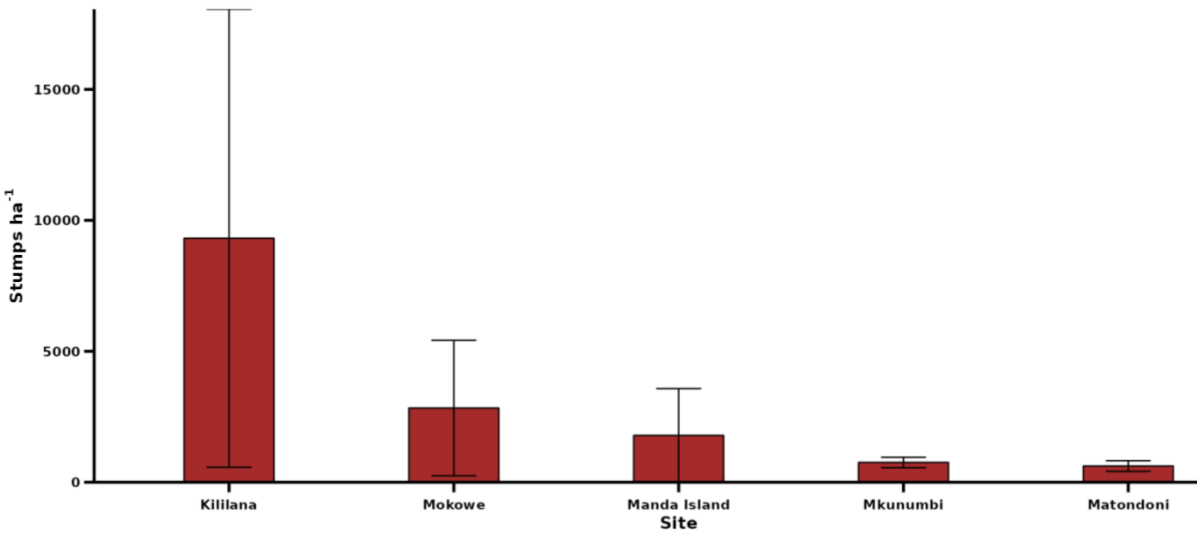


Figure 20: Stump density (counts ha^{-1}) of mangroves in Lamu Southern swamp

While the mangroves of the Lamu Southern swamp display some degree of disturbance, potential recovery through natural regeneration was noted. Juveniles were frequently found growing close to the mother tree in clusters. Density of juveniles ranged from 683±280 juveniles ha^{-1} in Mokowe to 6,525±2375 juveniles ha^{-1} in Matondoni (mean±s.e: 4,053±1,076 juveniles ha^{-1}). The forest was dominated by Regeneration Class I juveniles (45.4%) followed by RCII (29.6%) and the rest RCIII (Table 12). Of particular interest was Manda Island* which had no mature trees but regeneration, RCI was highest (4,200 counts ha^{-1}) representing 79.2%. This can be attributed to good seeding from nearby mother trees and tidal flows bringing in seeds into the degraded areas. Matondoni recorded the highest density of juveniles in RCIII, 3,075 ha^{-1}, representing 47.1% (Figure 21). The abundance of these saplings significantly contributes to their potential transition into mature trees, and therefore, they are considered established regeneration (FAO, 1994).

Kililana had high densities of RCI against low RCII and RCIII, typical of a naturally recovering system where many young ones are produced which undergo mortality as a few are recruited to subsequent classes. Low natural regeneration as witnessed in Mokowe could be attributed to extreme forms of disturbances but in this case, it was as a result of closed canopies limiting light penetration to the forest floor.

Table 12: Juvenile densities (counts ha^{-1}) of mangroves in Lamu Southern swamps

Site	**Regeneration classes**			**Total (Juveniles ha^{-1})**
	RCI (0-40 cm)	**RII (40.1-150 cm)**	**RCIII (150.1-300 cm)**	
Mkunumbi	1,636±961	2,044±1180	1,625±578	5,306±2,606
Matondoni	1,425±517	2,025±712	3,075±12	6,525±2,375
Mokowe	142±74	308±145	233±147	683±280
Kililana	1,792±908	517±303	142±71	2,450±1,276
Manda Island*	4,200±4,200	1,100±1,100	0±0	5,300±5,300
All combined	**1,839±658**	**1,199±365**	**1,015±592**	**4,053±1,076**
Potential regeneration category = RCI = 1,839 (45.4%) Established regeneration category = RCII + RCIII = 2,214 (54.6%)				

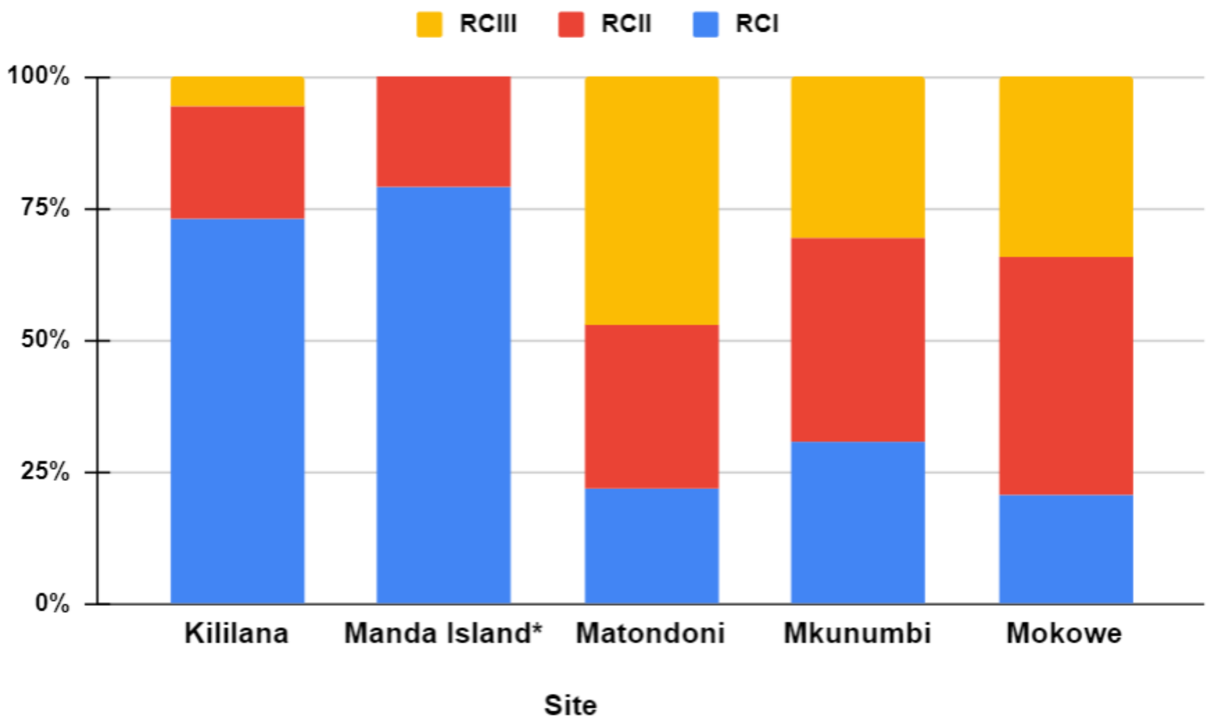


Figure 21: Proportions (%) of juvenile densities of mangroves in Lamu Southern swamps

6.3.2 Benthic Communities

Benthic communities refer to organisms associated with substrata/sediment in aquatic habitats and include gastropods (snails), annelids (polychaetes), crustaceans (copepods, amphipods), and nematodes (Simpson *et al.,* 2016). In addition to their trophic contribution, the structural complexity and habitat heterogeneity offered by mangrove microhabitats, i.e. pneumatophores or prop roots, provide excellent shelter to benthic fauna from predators (Macia *et al.*, 2003). The benthic invertebrates in turn help shape the structure and function of mangrove forests through bioturbation, organic matter processing, and propagule predation (Lee, 2008), representing an important role in nutrient recycling (Ashton *et al.,* 2003; Claudino *et al.,* 2015). Studies have shown that benthic fauna are excellent indicators of biotic integrity due to their abundance, high tolerance/sensitivity to different environmental stressors, wide distribution, and sedentary lifestyle with a relatively long life span (Bressler *et al.,* 2006).

Sampling and Analysis

Triplicate benthic fauna samples, up to a sediment depth of 10 cm, were randomly collected using a corer of transparent perspex tubing (diameter 3.6 cm). The samples were placed in well-labelled sample containers and fixed with 8% formaldehyde solution before transporting to the laboratory for observation under a dissecting microscope. The benthic organisms were identified to the lowest possible taxonomic level with the aid of relevant manuals and keys. The counts of different taxa groups were recorded for further analysis.

Findings

A total of 134,127.55 ind./m^2 belonging to 20 taxa were identified with a predominance of Oligochaeta (55.75%), Nematoda (30.89%), Nereididae (6.18%), Sabellidae (3.86%), and Terebellidae (0.77%), Capitellidae (0.39%), Collembola (0.39%), Harpacticoida (0.31%), Trichobranchidae (0.31%), Syllidae (0.23%), Polychaeta (0.15%), and Opheliidae (0.15%) were also identified see Figure 22. Cirratulidae, Hesionidae, Spionidae, Cumacea, Chironomidae, Holothuroidea, Nephtyidae, and Tanaidacea each comprised 0.08% of the total population, as they were recorded only once in the samples.

All values are presented as mean±SD (standard deviation), with the seaward zone recording the highest abundances of Oligochaeta (13,231.50±2054.79), Nematoda (8,441.23±6894.44), and Nereididae (1,398.24±1064.68), whereas the degraded sites had the lowest densities for Oligochaeta (2770.59±3284.41), Nematoda (1216.99±1576.17), and Nereididae

(336.61±258.93). The landward zone had the highest abundace of Sabellidae (1242.88±146.47) compared to the seaward zone (466.08±800.04) and the degraded sites (207.15±414.29). Notably, Polychaeta (51.79±59.80), Cirratulidae (25.89±51.79), Hesionidae (25.89±51.79), Terebellidae (258.93±517.87), and Collembola (129.47±258.93) were unique to the seaward zone.

Similarly, Holothuroidea (51.79±73.24), Nephtyidae (51.79±73.24), Tanaidacea (51.79±73.24), and Trichobranchidae (207.15±292.95) were unique to the landward zone. Spionidae (25.89±51.79), Cumacea (25.89±51.79), Chironomidae (25.89±51.79), and Opheliidae (51.79±103.57) were unique to the degraded sites. Only degraded sites and the seaward zone hosted Syllidae and Capitellidae, with higher Capitellidae densities in degraded sites (77.68±155.36) than in the seaward zone (51.79±59.80). However, the Syllidae density was higher in the seaward zone (51.79±59.80) compared to the degraded sites (25.89±51.79).

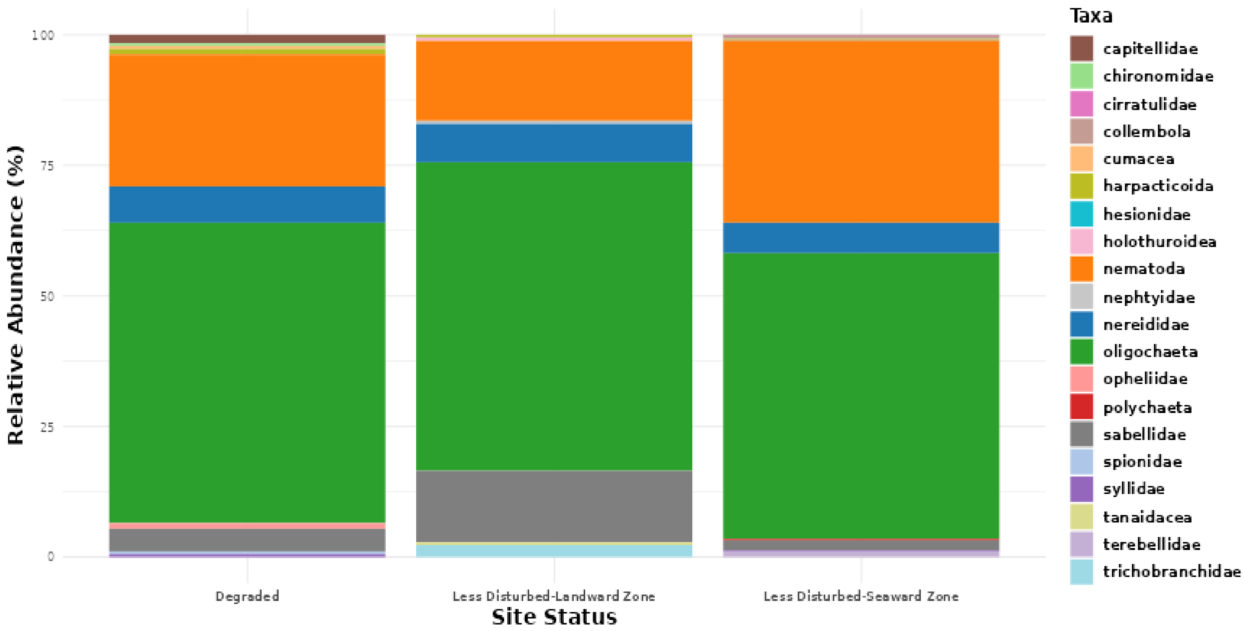


Figure 22. Relative abundance (%) of benthic taxa in the mangroves of the Southern Swamp

In summary, the seaward zone had higher taxa counts than the landward zone and degraded sites, clearly illustrating that sediment conditions on the seaward zone favoured greater numbers and diversity of benthic taxa. Across the study area, the Shannon-Weiner diversity index, Simpson's diversity index, Pielou's evenness index, and Margalef's species richness index were 1.18, 0.59, 0.38, and 1.86, respectively. Table 13 summarises diversity indices observed in the respective study sites. The Shannon-Wiener diversity indices implied that degraded sites (H' = 1.26) and landward zone (H' = 1.27) had a similar and higher diversity than the seaward zone which showed a slight decrease in diversity (H' = 1.08). Additionally, the Simpson's index indicated that the seaward zone (D = 0.574) had higher dominance of certain species suggesting that some taxa were more prevalent thus reducing the overall diversity. Degraded sites (D = 0.598) and the landward zone (D = 0.603) were relatively similar indicating that they had comparable community structures. Based on Pielou's evenness index values, degraded sites (J' = 0.527) and the landward zone (J' = 0.576) showed a balanced distribution of taxa, however, the seaward zone (J' = 0.443) lacked a balance in species distribution suggesting that its environmental conditions favoured specific taxa over others. Degraded sites (d = 1.01) showed the highest species richness, suggesting a well-diversified benthic community. The seaward zone (d = 0.958) had an intermediate species richness; however, the landward zone (d = 0.815) had the lowest species richness indicating less diversity in terms of the number of different species present.

Table 13: Diversity indices recorded in the degraded, less disturbed-landward zone, and less disturbed-seaward zone study sites

Site Status	**Shannon-Wiener Index (H')**	**Simpson's Index (D)**	**Pielou's Evenness Index (J')**	**Margalef's Species Richness (d)**
Degraded	1.26	0.598	0.527	1.01
Less disturbed-Landward Zone	1.27	0.603	0.576	0.815
Less disturbed-Seaward Zone	1.08	0.574	0.433	0.958

6.3.3 Avifauna (birds) Survey

Due to their sensitivity to environmental changes, birds are key bioindicators of ecosystem health. Changes in bird populations, diversity, and behaviour often reflect alterations in habitat structure, pollution levels, and food availability. Migratory birds, in particular, can signal changes across different ecosystems as they shift between regions. By identifying certain bird species, scientists can deduce the degradation level and health status of the habitat in question. In this study, an avifauna survey was conducted using two classical assessment techniques: point counts along line transects, and total (absolute) counts. For the point counts, observers walked along designated transects, stopping at stations spaced 200 m apart for 10 minutes to record all birds seen or heard within a 50 m radius. The total (absolute) counts involved documenting all birds observed roosting or feeding within a given point in the survey area, following the approach outlined by Musina *et al.*, (2014).

Findings

A total of 1,443 birds were observed across the sampled area in Lamu Southern Swamp Mangrove forest (Supplementary_1). More individual birds were counted in mangrove forest near Matondoni (n = 654) compared to Manda Maweni (n = 421) and Mkunumbi (n = 368), Fig.23(a). Generally, the sampled areas exhibited high avian diversity. Unlike Matondoni, which had relatively high species dominance and evenness, Mkunumbi exhibited relatively high species richness and evenness (Fig. 23(d)), while Manda Maweni had relatively high species richness (Fig.23(b)). Although these results highlight variations in avian diversity and richness around the forest block, further temporal surveys are required for accurate determination of the true avian diversity in the area.

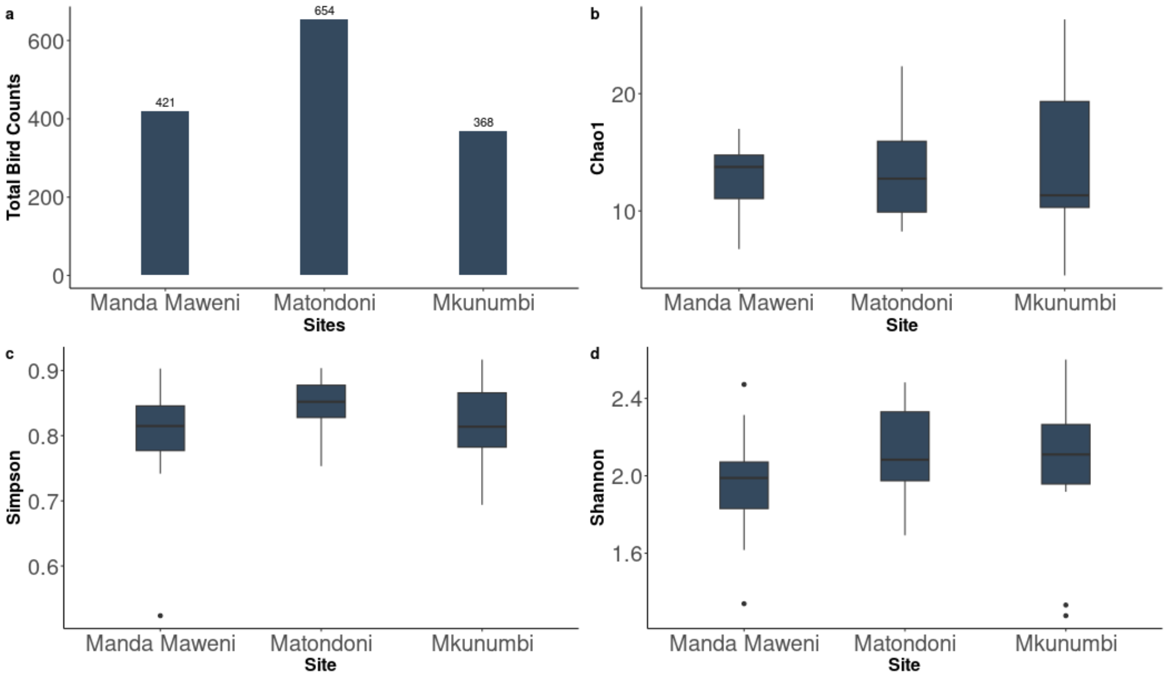


Figure 23: Cumulative bird counts and alpha diversity indices. a) number of birds recorded at each site, b) species richness as estimated by Chao1, c) species diversity as estimated by Simpson index, and d) species diversity as estimated by Shannon index.

Avian Taxonomic Composition and Profile

A total of 86 species belonging to 68 genera, 36 families, and 12 orders were recorded during the survey. The order *Passeriformes* had the highest species representation (n = 37), followed by *Charadriiformes* (n = 16). In contrast, the order *Perciformes* was the least represented, with only one species identified, see Supplementary 1.

Birds of Conservation Concern

A total of seventy-four (74) bird species considered to be migrants were recorded during the survey. Of these, nine (9) are known Afro-tropical (AM) migrants, 17 were Palearctic migrants (PA), and 48 partial migrants (PM). Similarly, one non migratory (NM), and 11 resident birds were equally identified, Figure 24.

Based on the intrinsic values of the forest to the identified bird species, the majority, 47, were categorised as forest visitors (f), 26 as None forest dependent (Non-F), 11 as forest generalist (F), and 2 as Forest specialist (Supplementary 1).

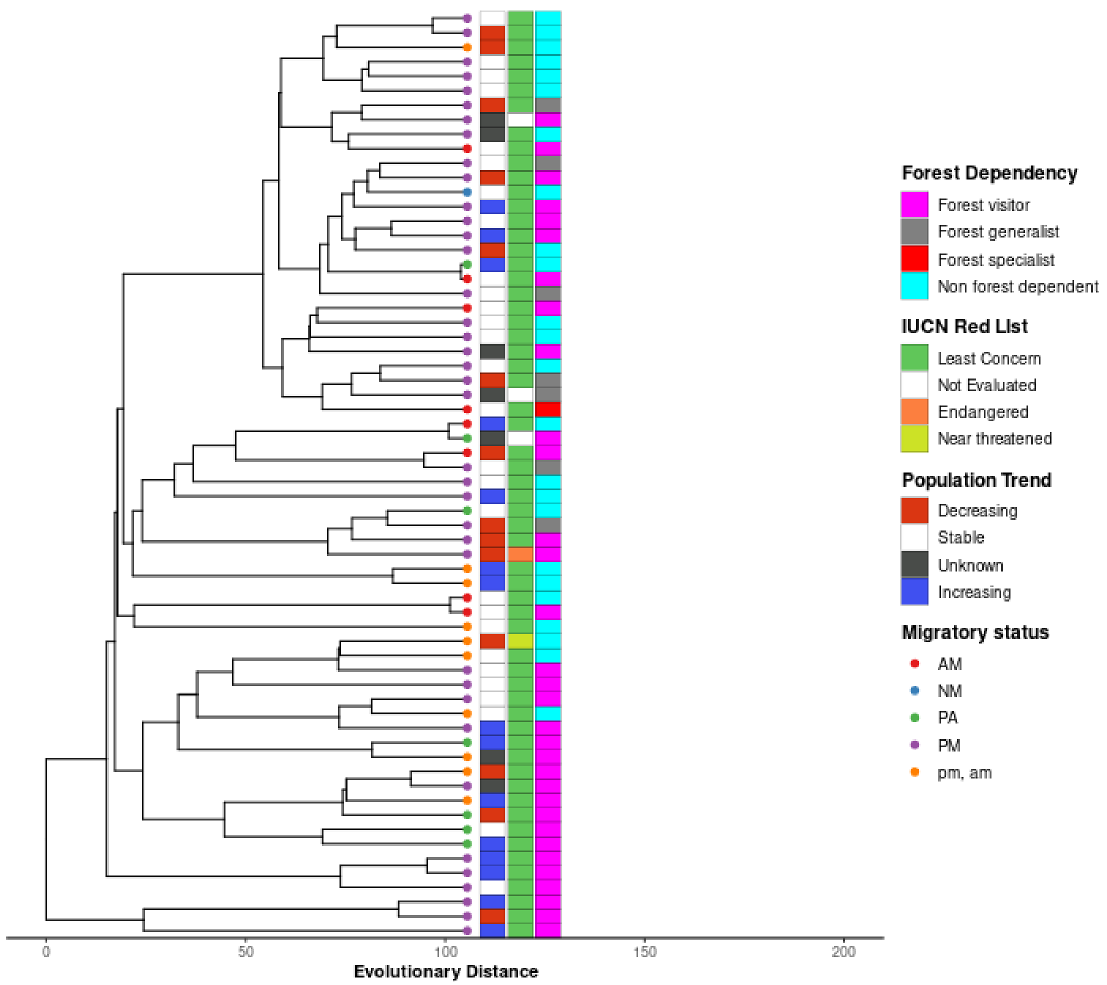


Figure 24: Phylogenetic tree and associated information on the migratory status, IUCN Red List status and the population trend of the identified bird species.

Key Threats to Birds Diversity and Population

The results affirm that Lamu mangroves, specifically the Southern Swamp, is key stopover habitat for migratory birds, and home to numerous non-migratory bird species. Despite being relatively undisturbed, the forest faces increased pressure emanating from anthropogenic activities. Several ongoing activities deemed detrimental to the habitat and its associated biodiversity were observed. Three anthropogenic activities which encompassed land use systems, deforestation, human settlement and one natural driver, that is soil erosion, were identified as direct threats to bird diversity.

These findings reflect on bird population and distribution within the surveyed areas. At Manda Maweni, the activities linked to bird population decline were land use activities including mangrove cutting, quarrying, and erosion. In Matondoni, notable threats were deforestation, erosion and land use activities, though at considerable proportions. Erosion and land use activities were more pronounced in the Mkunumbi area. It is worth noting that, overall, the pressure on biodiversity in Lamu mangrove forest is on the rise, potentially being exacerbated by overexploitation and the impact of climate change.

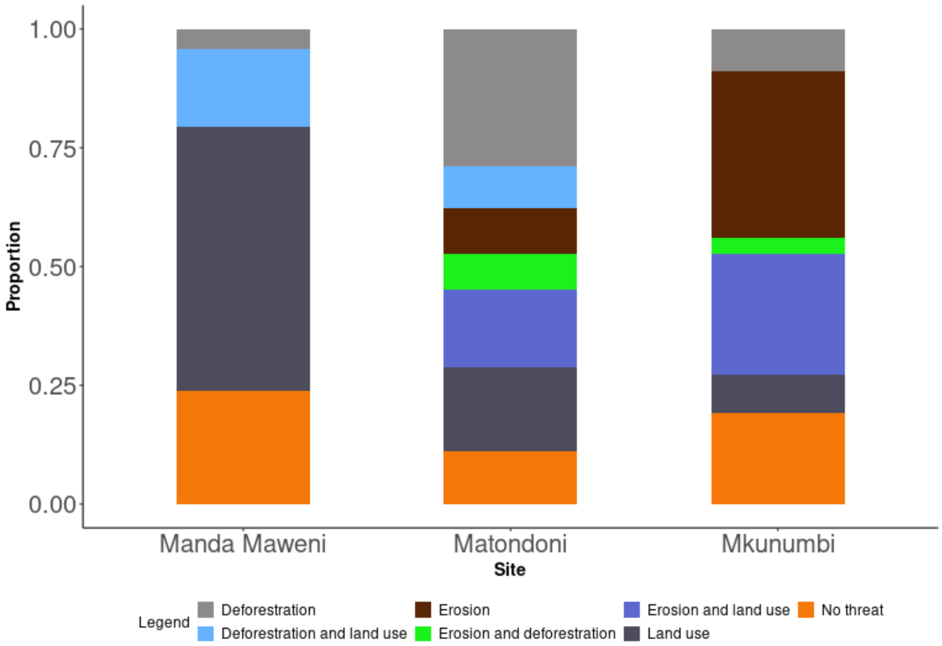


Figure 25: Proportions of the identified threats documented in the surveyed sites during the study period

6.3.4 Application of Environmental DNA (eDNA) Technique

Environmental DNA (eDNA) refers to organismal or extra-organismal genetic material obtained from environmental sample matrices. It provides a non-invasive means for detecting and monitoring biodiversity, offering great insights into ecosystems biodiversity status, trophic linkages and networks. eDNA provides a snapshot on biodiversity landscape and shifts occasioned by ecological changes.

During this survey, samples were collected along the mangrove channels following the recommendation and standard methods by Miya & Sado, (2019). All the samples were transported to the laboratory where they were processed, filtered and temporarily kept at -80°C prior to DNA extraction. The DNA was extracted from the samples using Zymogen kit following the manufacturer's protocol. After quality checks, the samples were sent to Inqaba Biotec East Africa for shotgun sequencing. Bioinformatics analysis was performed following the established Kraken pipeline and the resulting taxa list was analysed in R.

Findings

A total of 31,187,297 sequence reads were generated from the 36 eDNA samples. Most of the reads (98.11%) could not be assigned to any taxonomic level using the NCBI organelle and microbial databases. Only a fraction, 1.89% (590,175 reads) were successfully matched and classified into some level of taxonomic hierarchy. Of the classified reads, 79.98% (472,044 reads) were identified as belonging to taxa in the Kingdom Bacteria, while 16.91% (99,803 reads) were linked to viruses and archaea. The remaining 3.11% (18,328 reads) were assigned to Eukaryotes, with animalia and plantae comprising 1.82% (10,128 reads), followed by fungi at 1.26% (7,427 reads), and protozoans having 0.13% (773 reads). Taxonomic assignment was confidently resolved to the genus level; however, species-level resolution could not be ascertained due to limitations in the existing global barcode databases.

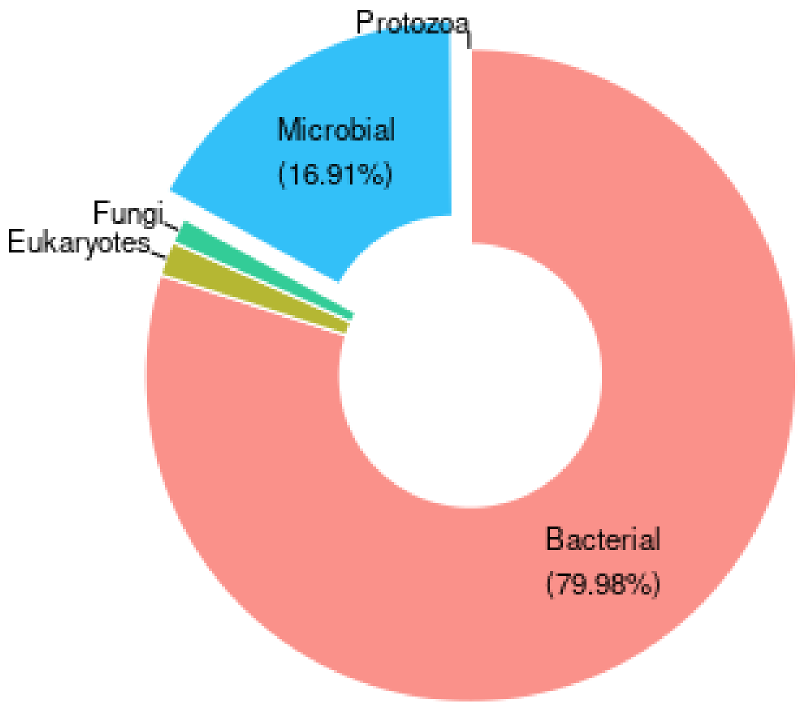


Figure 26: Proportion of sequence reads assigned to some level of taxonomic hierarchy

Phyla relative abundance based on assigned reads

The positively assigned reads, 590,175, were correctly used to identify a total of 8,231 unique taxa with varying levels of sequence read abundance (Fig. 27). Notably, 97.181% (7,999 taxa) of these taxa were successfully matched to updated records in the Global Biodiversity Information Facility (GBIF). These taxa were distributed across 6 kingdoms, 65 phyla, 2,295 families, and 5,524 genera. The most dominant phyla, each with relative sequence read abundance above 18%, included *Proteobacteria*, *Actinobacteria*, *Firmicutes*, *Tracheophyta*, *Chlorophyta*, *Chordata*, and *Arthropoda.*

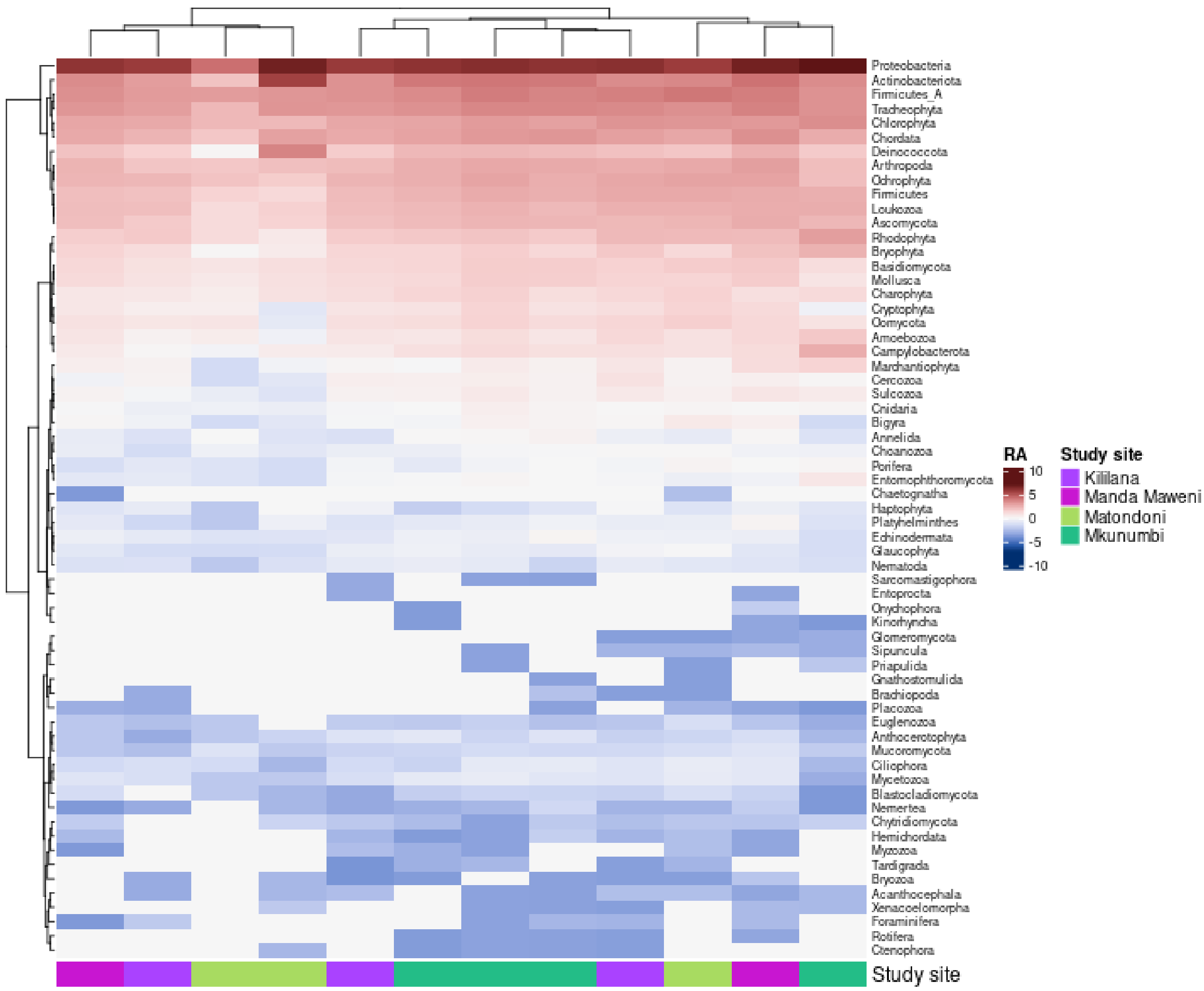


Figure 27: Relative abundance of sequenced reads at phyla level for eDNA samples from Kililana, Manda Maweni, Matondoni, and Mkunumbi. (*Legend: RA - Relative abundance)*

Biodiversity Snapshot as Depicted by Environmental DNA Survey

Mangrove forest, as an interface ecosystem, is a reservoir of genetic material for both aquatic and terrestrial species. In this study, eDNA analysis revealed the presence of mixed taxa native to aquatic and terrestrial ecosystems in varying proportions. These mixed genetic inputs, particularly from terrestrial ecosystems, are typically introduced by mobile species, such as birds, and/or carried by rivers and floodwaters. As a result, the taxa profile not only represents local biodiversity but also reflects contributions from neighbouring ecosystems. Notably, 82.65% of the identified taxa were not documented as marine species.

Among the taxa identified, Animalia had the highest representation, accounting for 81.91% (n = 6,570) of the total taxa. Plantae accounted for 7.54% (n = 605), fungi 6.82% (n = 547), Chromista 2.62% (n = 210), and Bacteria 0.62% (n = 50). Protozoans had the lowest, accounting for 0.42% (n = 34) of the total number of the identified taxa, see Table 14.

Table 14: Summary of taxa identified from Lamu Southern swamp mangroves

Kingdom	**Phylum**	**Class**	**Order**	**Family**	**Genus**	**Species**	**Total**	**RA**
Protozoa	7	16	17	26	29	34	**34**	**0.42%**
Plantae	8	38	127	226	449	605	**605**	**7.54%**
Fungi	7	24	57	147	291	547	**547**	**6.82%**
Chromista	9	24	50	76	111	210	**210**	**2.62%**
Animalia	29	79	352	1796	4608	6570	**6570**	**81.91%**
Bacteria	5	7	19	23	35	50	**50**	**0.62%**
Total	**65**	**189**	**623**	**2295**	**5524**	**8016**	**8016**	

Phyla Abundance and Prevalence

Cumulatively, a total of 65 phyla encompassing taxa from terrestrial and marine ecosystems were detected across the sampled sites in varying relative abundance and prevalence. The most prevalent and abundant phyla included *Tracheophyta, Chordata, Chlorophyta, Arthropoda*, *Ascomycota*, *Basidiomycota*, *Marchantiophyta*, *Ochrophyta*, *Rhodophyta*, *Oomycota*, *Mollusca*, and *Porifera*. These phyla were consistently detected across the sampled locations. In contrast, several phyla namely, *Tardigrada*, *Orthonectida*, *Nematophora*, *Perkinsozoa*, *Tubulinea*, *Onychophora*, *Deinococcota*, *Sulcozoa*, *Placozoa*, *Kinorhyncha*, *Euglenozoa*, *Gnathostomulida*, and *Gastotricha*, were far less prevalent and exhibited significantly low prevalence and abundance across the sample sites (Fig. 28).

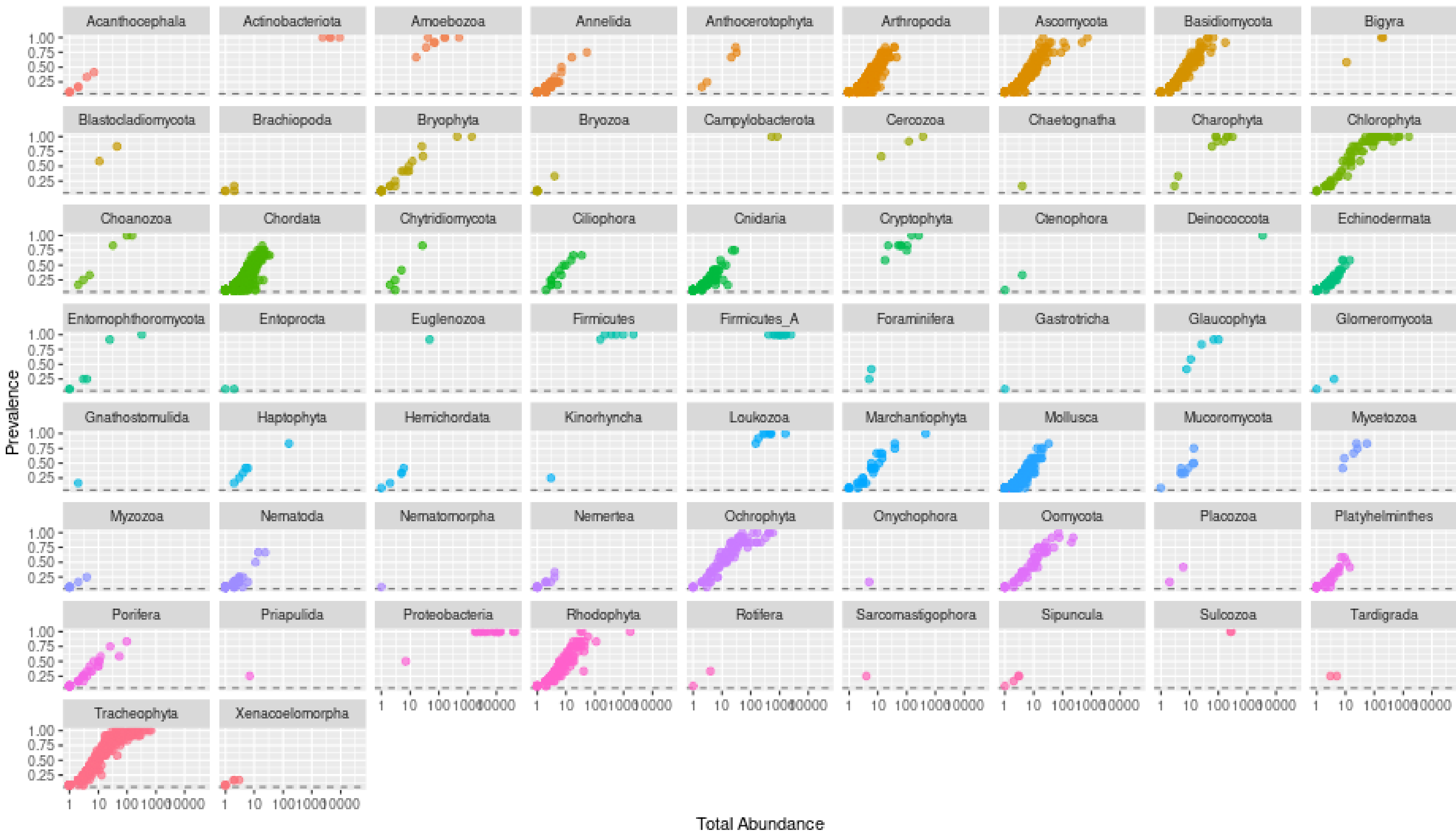


Figure 28: Phyla prevalence and relative abundance across the sampled sites

Marine Taxa Composition and Profile

The proportion of identified marine taxa varied across sampling sites. Although no significant variation was detected in taxa composition at the phylum level, notable differences emerged in the relative proportions of taxa profiles (Fig. 29). A total of 1,428 taxa were identified, spanning 98 classes, 703 families, and 1,126 genera. The Kingdom Animalia was the most represented, with 1,193 taxa, followed by Plantae (86 taxa), Chromista (63 taxa), Bacteria (50 taxa), Fungi (12 taxa), and Protozoa (6 taxa). These taxa distributions exhibited variability across the different sampling sites and replicates.

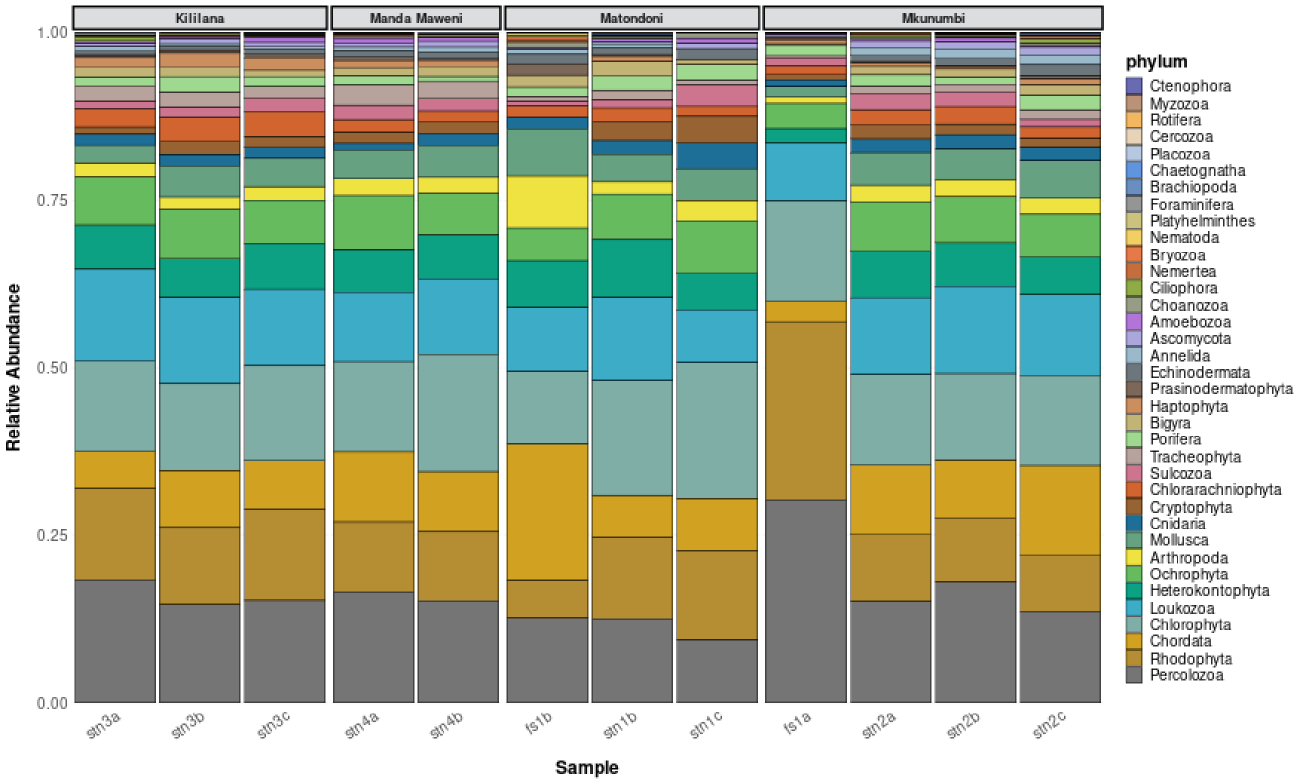


Figure 29: Relative abundance and taxa profile of sampled sites across sample replicates

The biodiversity status of the four sampled sites, as depicted by the Shannon alpha diversity index, was consistently high, with values exceeding 3.0 (Fig. 30). This may, in some way, suggest that the habitats are taxa rich, with a well-balanced mix of evenly distributed species. Despite the overall high diversity some sites, like Matondoni, exhibited higher Shannon value, indicating slight variations in species dominance. These variations may be attributed to ecological degradation and/or technical errors in the eDNA processing pipeline.

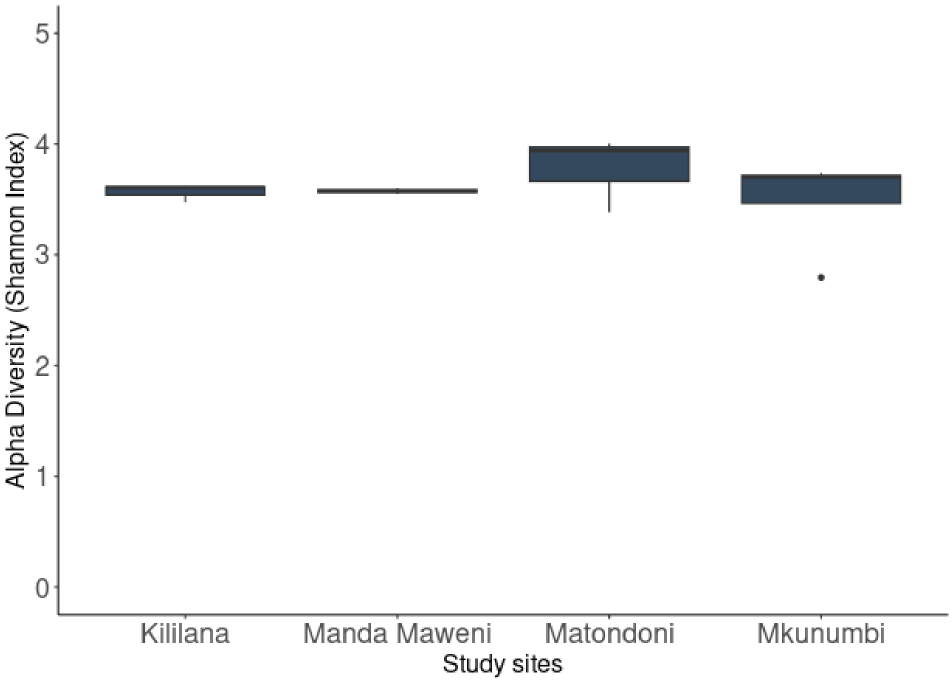


Figure 30: Taxa alpha diversity as estimated by Shannon diversity index

Family Composition

A total of 703 families belonging to 6 kingdoms were identified using the eDNA survey. The Kingdom Animalia was the most diverse, represented by 288 families, followed by Chromista (n = 37), Plantae (n = 35), and Bacteria (n = 30). Fungi and Protozoa were the least represented with 10 and 6 phyla, respectively.

Kingdom Animalia

The Kingdom Animalia was dominated by the families, namely, Carangidae, Gobiidae, Conidae, Bothidae, Balanidae, Lutjanidae, Balistidae, Blenniidae, Chromodorididae, Macrouridae, Cottidae, Dasyatidae, Labridae, and Lineidae with a relative abundance ranging from 2. 25% (n = 12) for Carangidae to 1.125% (n = 6) for Lineidae. Others such as Alepocephalidae, Macrophthalmidae, Muchilidae and Luidiidae had relative abundance below 1.0% (n ranging from 5 to 1), see Supplementary 2.

Kingdom Plantae

In the Kingdom Plantae, the most dominant families identified were Gracilariaceae, Rhodomelaceae, Bangiaceae, Ulvaceae, and Grateloupiaceae, with relative abundances of 19.77%, 11.63%, 8.13%, 6.98%, and 5.81%, respectively. In contrast, the least abundant families included Bathycoccaceae, Bonnemaisoniaceae, Caulerpaceae, Chlorarachniaceae, Chlorodendraceae, Chloropicaceae, Corallinaceae, Delesseriaceae, Endocladiaceae, Gelidiellaceae, Hapalidiaceae, Mamiellaceae, Ostreobiaceae, Picocystaceae, Porolithaceae, Porphyridiaceae, Prasinodermataceae, Pycnococcaceae, Pyramimonadaceae, Rhizophoraceae, Spongitidaceae, Sporolithaceae, and Uronemataceae, all with a relative abundance of 1.163% (n = 1), see Supplementary 2.

Kingdom Fungi

The Kingdom Fungi was represented by ten families: Orbiliaceae, Chaetomiaceae, Cladosporiaceae, Cordycipitaceae, Debaryomycetaceae, Diaporthaceae, Helotiales, Saccharomycetaceae, Saccharomycetales, and Stachybotryaceae, all exhibiting equal relative abundance, see Supplementary 2.

Kingdom Chromista

The families Sargassaceae and Naviculaceae had the highest representation, with relative abundances of 19.04% (n = 12) and 6.30% (n = 4), respectively. The other families in this kingdom included Alariaceae, Geminigeraceae, Laminariaceae, Monodopsidaceae, Scytosiphonaceae, Fucaceae, Skeletonemaceae, Acinetosporaceae, Agaraceae, Cafeteriaceae, Calcarinidae, Cercomonadidae, Chordariaceae, Coscinodiscaceae, Cymatosiraceae, Dictyotaceae, Halteriidae, Hemiaulaceae, Holophryidae, Isochrysidaceae, Lessoniaceae, and Lithodesmiaceae. See Supplementary 2 additional illustration.

Kingdom Protozoa

The Kingdom Protozoa comprised six families, each with equal relative abundance. These families were: Ancyromonadidae, Andaluciidae, Apusomonadidae, Nucleariidae, Paramoebidae, and Tulamoebidae.

Kingdom Bacteria

A total of 30 bacterial families were identified. Eubacteriales was the most dominant with a relative abundance of 22.06% (n = 15), followed by Enterobacteriaceae 11.76% (n = 8). Lactobacillales and Sphingomonadaceae were equally represented, each accounting for 7.35% (n = 5) of the identified bacterial families. In contrast, families such as Vibrionaceae, Xanthomonadaceae, Yersiniaceae, Zavarziniaceae, and Sutterellaceae had the lowest relative abundances, each accounting for 1.47% (n = 1) of the bacterial composition (Supplementary 2).

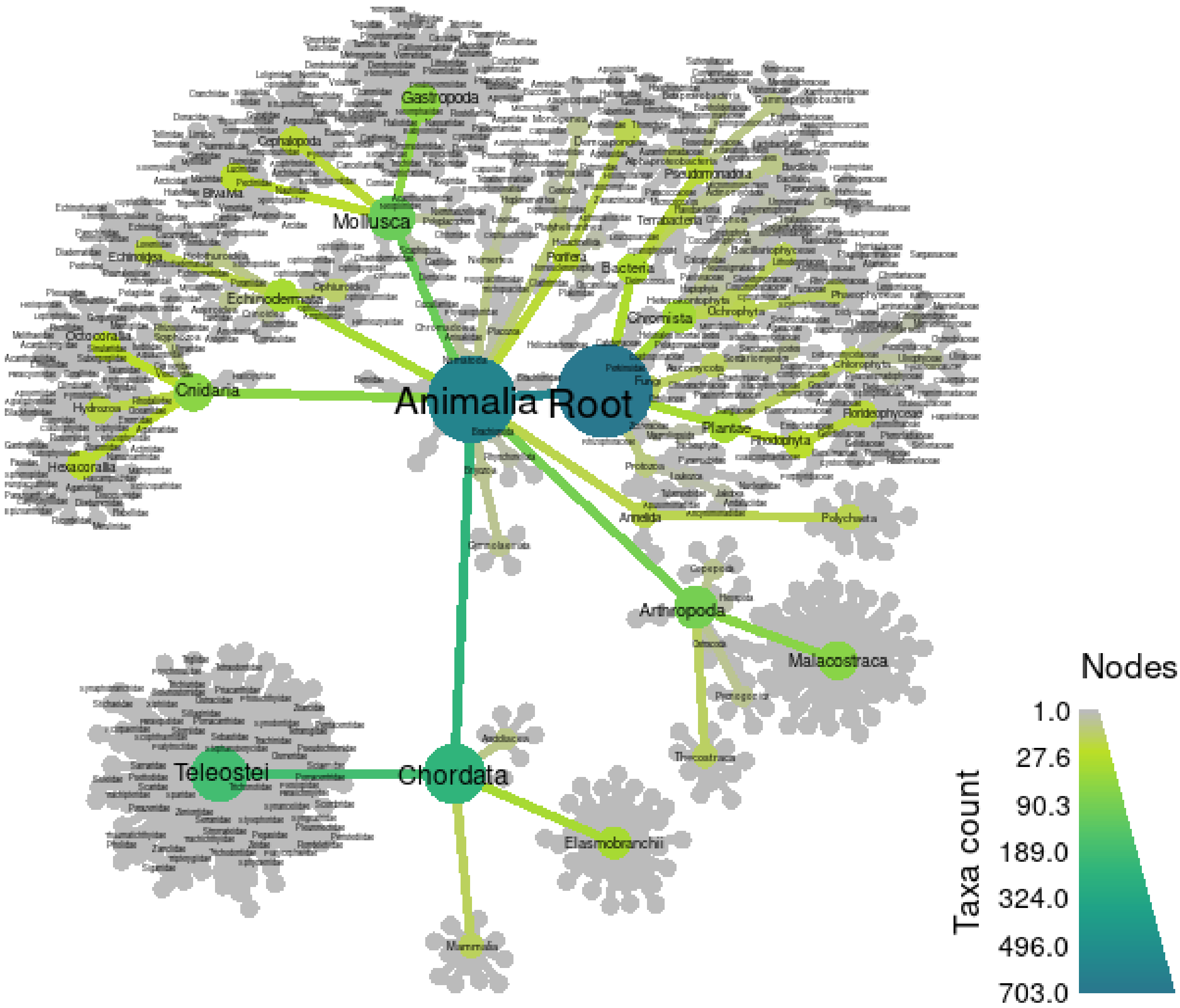


Figure 31: Rooted tree of overall biodiversity in Lamu Southern Swamp mangroves based on eDNA survey results

Limitations of eDNA in biodiversity survey and ecological monitoring

Studies have shown that the environmental DNA (eDNA) surveys can greatly complement classical techniques in biodiversity assessment and ecological monitoring (Deiner et al., 2017; Couton *et al.*, 2023). However, the technique comes with number of constraints including, but not limited to:

1. Taxonomic resolution: Due to the similarities in genetic markers eDNA can struggle with identifying species down to precise taxonomic levels, especially when reference databases are incomplete or poorly curated. This often limits identification to species level
2. Short DNA fragment degradation: Environmental conditions such as UV light, temperature, and pH can degrade DNA quickly. This may cause underrepresentation

of certain species, particularly in environments with harsh conditions, resulting in biased conclusions about species presence or abundance.

3. Temporal and spatial limitations: eDNA only provides a snapshot of the biodiversity at the time of sampling, without indicating when or where the species were exactly present. This limitation makes it difficult to differentiate between resident species and transient or migratory organisms, as well as between live organisms and dead material.
4. Incomplete reference databases: Success in identifying species depends heavily on comprehensive reference databases. Gaps in these databases, particularly for non-model organisms or understudied regions, can limit the accuracy of eDNA results.
5. Differential DNA shedding: Different species shed DNA at varying rates depending on their size, physiology, and activity levels. This variation can cause some species to be over- or underrepresented in eDNA samples, potentially skewing biodiversity estimates.

Endemic and Species of Conservation Concern

Lamu's mangrove forests and surrounding habitats serve as a critical refuge for numerous species of conservation concern (Gereau *et al.*, 2016). In this survey, using both primary and secondary techniques, 55.38% (4,513) of detected species were classified as Not Evaluated (NE) and are yet to be incorporated into the IUCN Red List. Of the remaining species, 33.37% (2,719) were categorized as Least Concern (LC), 2.47% (202) as Endangered (EN), 2.16% (176) as Near Threatened (NT), 3.17% (258) as Vulnerable (VU), and 2.21% (180) as Data Deficient (DD). Several species of high conservation priority were identified, including *Charadrius mongolus* (EN), *Ciconia episcopus* (NT), *Torgostracheliotos* (EN), *Terathopiusecaudatus* (EN), *Trigonoceps occipitalis* (NE), *Necrosyrtesmonachus* (CR), *Eretmochelys imbricata* (CR), and *Polemaetusbellicosus* (EN). While some species, aside from those identified through eDNA and primary surveys, were not directly recorded in the Lamu Southern Swamp mangrove forest, they are closely associated with mangrove ecosystems and integral to the biodiversity of Lamu’s mangrove habitats.

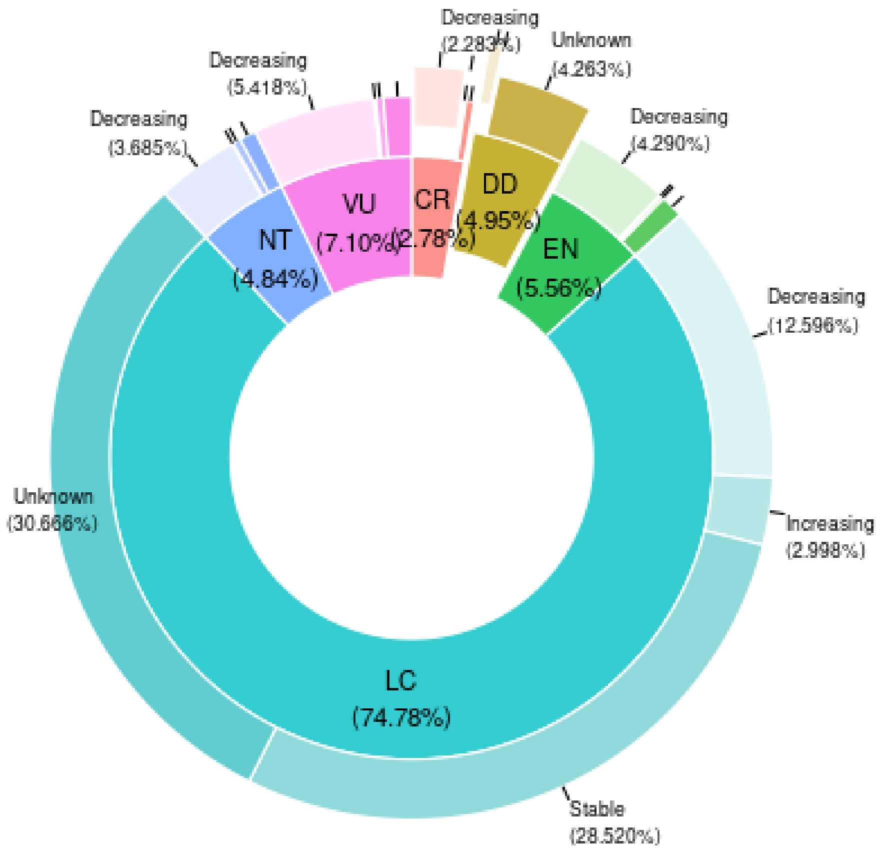


Figure 32: Species of conservation concern from Lamu Southern swamp Mangroves

The reviewed documents reveal that Lamu's forest biodiversity is both understudied and disproportionately focused on plants and animals, leaving significant gaps in the overall understanding of its ecosystems. Despite comprising over 60% of Kenya’s mangrove forest cover, Lamu’s biodiversity remains critically underrepresented in current studies. Notably, though species-level resolution was limited, with less than 1% of sequenced reads classified, eDNA surveys have provided valuable insight into the biodiversity of the Lamu Southern Block mangrove forest. These findings surpass previous knowledge and hint at potential trophic interactions within the ecosystem. To support informed management and conservation efforts, it is imperative to gather more comprehensive biodiversity data from Lamu’s mangrove forests.

Chapter 7: Development of Baseline and Restoration Scenarios

7.1 Introduction

This chapter presents the baseline scenarios relating to the climate and environmental conditions of the Lamu Southern swamp including the mangroves forest cover, carbon stock and sea level rise. The analysis under this section aimed to develop baseline and restoration scenarios for evaluation of potential climate change mitigation benefits of mangrove restoration by making use of existing land use maps, carbon stock data per land-use class, topographic data and local sea level rise projections among other important environmental change drivers. The analysis further provides projections and scenarios of change into the future. We particularly pay close attention to the climate drivers and how they may change over time. In the end, the section proposes restoration programs and scenarios for different restoration requests which the communities as well as government and development partners may use to approach restoration of degraded mangrove ecosystems. Figure 33 provides an illustration of how changes in climate and atmospheric composition may impact mangrove ecosystems by exacerbating other extreme effects such as sea level rise, changing ocean currents, increased storminess, increased temperature, changes in precipitation and increased CO_2.

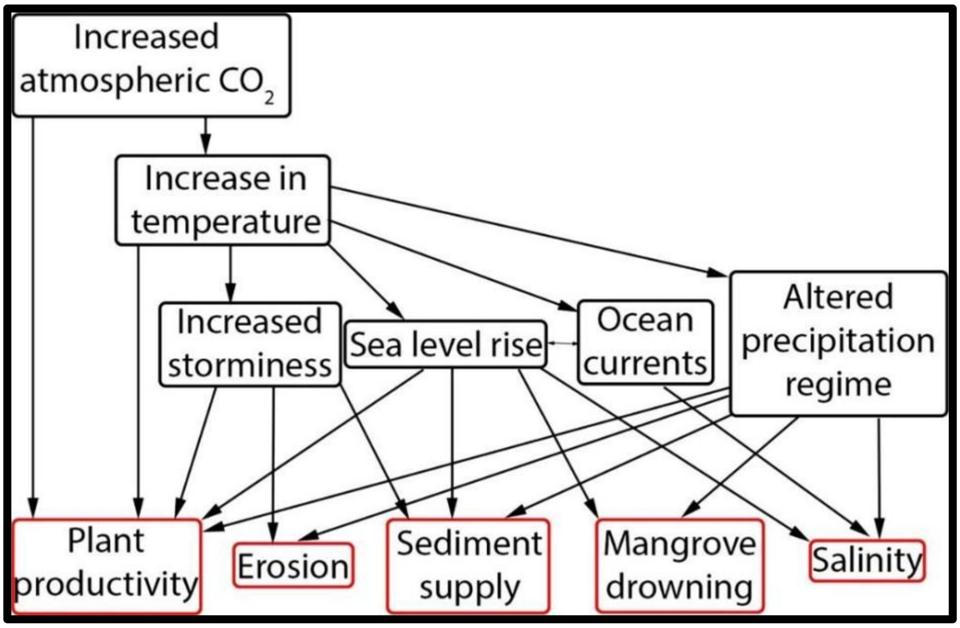


Figure 33: Climate impacts on Mangroves – conceptual framework (Source MangroveWatch 2024)

7.2 Approach to Assessment of Baseline and Future Climate Risks for Lamu Southern swamp

Changing climate conditions has significant influence on the restoration outcomes of degraded mangroves, for this reason the study assessed to establish the changing climate situation of Lamu southern Swamp by assessing change and future trends for various climate variables. The main climate parameters assessed in this study included temperature, rainfall and drought as well as sea level rise. Projected precipitation and heat days above 35°C were downscaled from CMIP 6 0.25-degree time series for 2015 – 2100-year period under scenarios SSP 126 and SSP585 ensemble (Lyon, 2020). In addition, the study used climate data (temperature and precipitation) obtained from the Kenya Meteorological Department (KMD). Further, spatial information and climate hazards (floods and droughts) were analysed. Simulated climate data and projections were obtained from different models such as 30-year Climate Hazards Center InfraRed Precipitation with Station data (CHIRPS) global rainfall dataset, fifth generation ECMWF atmospheric re-analysis (ERA5), Climate Research Data (CRU), and European Space Agency (ESA) Copernicus, among others.

Observed as well as global models were used to estimate sea level rise for Lamu. Sea level rise was analysed from Copernicus using the Operating on DT merged two satellites Global

Ocean Gridded SSALTO/DUACS Sea Surface Height L4 product and derived variables interpolating points lon= 40.625 40.875, lat= -2.375 -2.125, sla [m] Sea level anomaly.

7.2.1 Climate Change and Risk Assessment Results

Temperature and Precipitation Baseline Trends

Temperature and rainfall may affect the restoration processes and growth dynamics of mangroves. Global temperature has a direct relationship on the water temperature which further has implications on the quality of water to support biodiversity. The changing temperature may affect nutrient dissolution and geochemical nutrient cycles. On the other hand, precipitation provides freshwater recharge into the terrestrial environments which also influences the saltwater balance between the boundary environments, a critical factor in the survival of mangrove species across the world. Understanding the changing temperature and precipitation trends, present and future scenarios may be useful in recommending appropriate measures for sustainable action.

Lamu County has a generally hot and dry climate with a mean annual temperature of above 25°C in most parts of the county and mean annual rainfall averages 900mm per year. The central regions of the county receive highest rainfall totals sometime averaging over 1000 mm per year while the north-eastern parts receive an average of between 500 and 1000 mm on average and a pocket in the south receiving lowest average annual rainfall of less than 250 mm in some places. Heat stress, dry spells, and drought are hazards that strongly contribute to agricultural risk in the county.

Analysis of average annual rainfall, measured over the same period (1990-2019), showed a declining mean annual rainfall over a 42-year period over the Lamu bay and the island (Figure 34). This decline in precipitation may be attributed to the slow effect of climate change which has resulted in decreased rainfall across the country. The results correlate with various predictions for the coastal areas which agree that there will be a drop in the mean annual precipitations in many areas including at the coast (Painter *et al.,* 2022; Hersbach *et al.,* 2020; Nicholson, 2017). With the reduced rainfall amounts, critical ecosystems like mangroves maybe affected especially due to the lack of enough freshwater mixing.

It is also important to note that seasonal variability across the year has a significant effect on ecosystems, the analysis shows slight changes in the first season rainfall (MAM) although second season rainfall averages have not changed significantly.

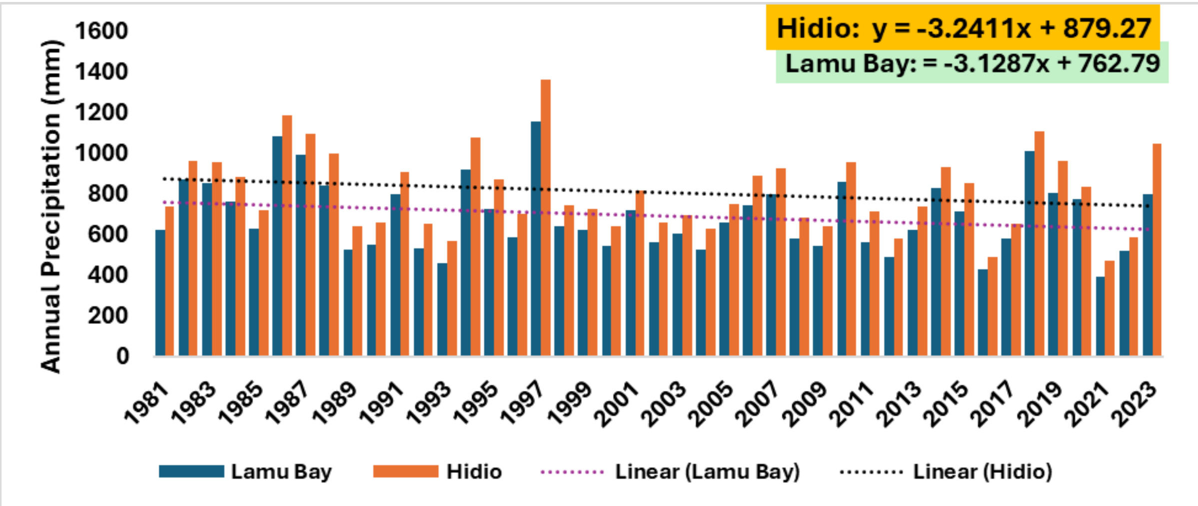


Figure 34: Historical rainfall patterns and trends over the Lamu Southern Swamp

Analysis of maximum annual temperature trends in the study areas showed an increase of approximately 2°C over the 30 year period (1990 to 2019), see Figure 35, this has subsequently led to increased levels of heat days which has risen steadily over the same 30 year period. With the increase in the number of heat days, severity and frequency of occurrence, the resultant. Generally, the increases in temperature and reduction of first season rainfall have resulted in an increase in the number of heat stress days in both seasons along with an increase in drought risk.

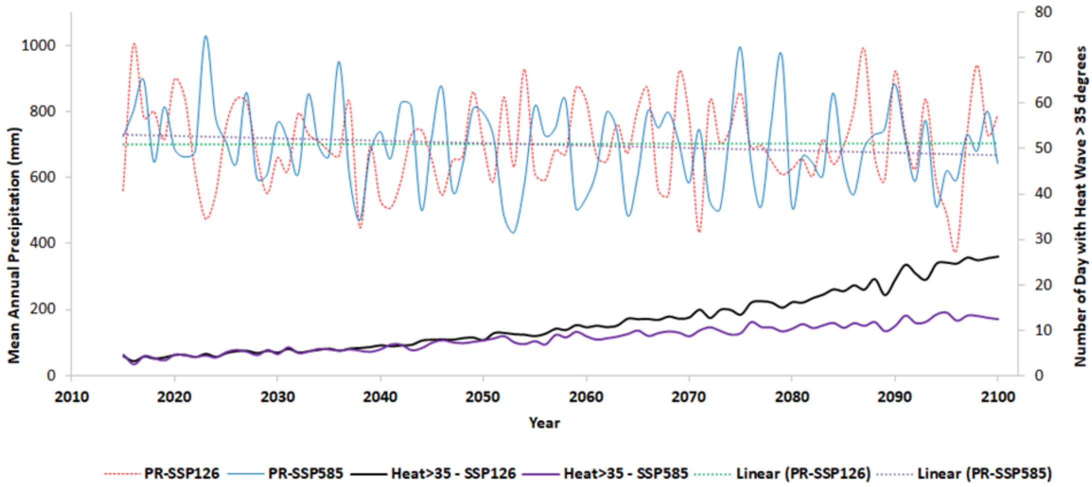


Figure 35: Historical and Future Precipitation and Heat Stress Trends in the Lamu Southern Swamp

This study further assessed the rainfall distribution within the Lamu southern swamp and extracted a spatial rainfall map shown in Figure 36. The maps show that rainfall is not uniformly distributed with rainfall patterns ranging from 500 to about 1000mm in annual amounts. The southern part of the AOI showed increased wetness in the future.

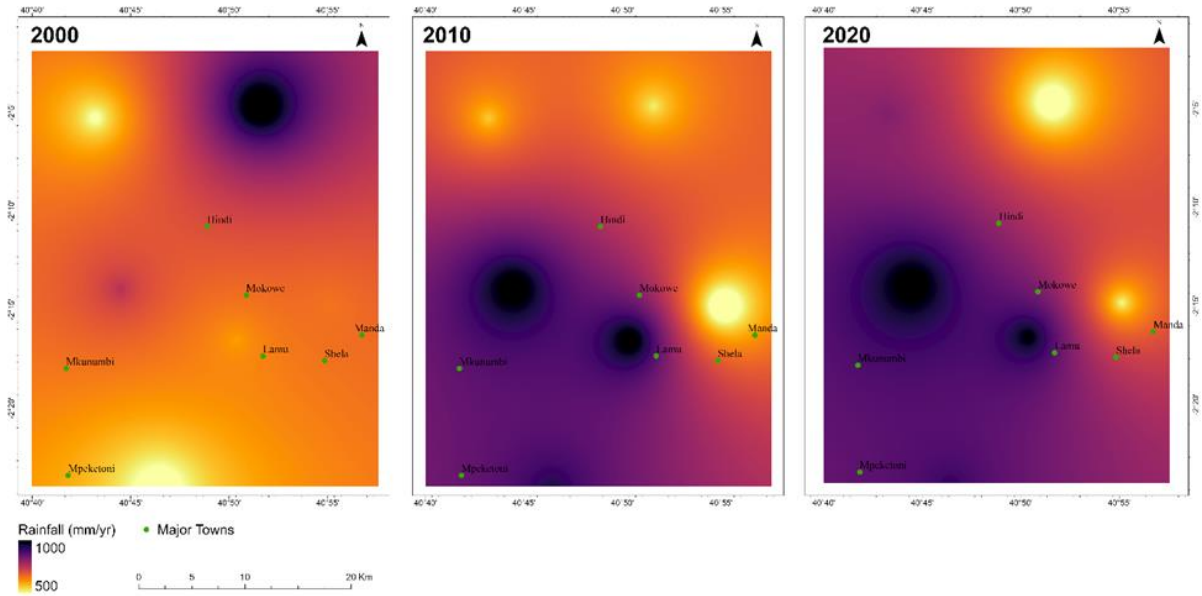


Figure 36: Rainfall distribution pattern in the Lamu Southern swamp

Sea Surface Temperature

Sea surface temperatures, just like air temperatures, may impact mangroves and marine life in general. Analysis of the daily sea surface temperatures over the Matondoni channel using the KNMI Climate Explorer and NOAA/NCDC is presented in Figure 37. The results indicate an increasing trend of sea level rise with some significant leap above the zero level suggesting positive anomalies. Sea surface temperatures is a direct reflection of the state of the atmospheric temperatures above the water surface which has persisted for some time. Changes in sea surface temperature may influence various physicochemical and biological processes in water including in mangrove ecosystems (Nicholson, 2019). In most cases, shifts in the sea-surface temperature may negatively affect the growth and productivity of mangrove ecosystems as it directly impacts on oxygen concentration and the salt balance which is likely to increase due to higher evaporation rates.

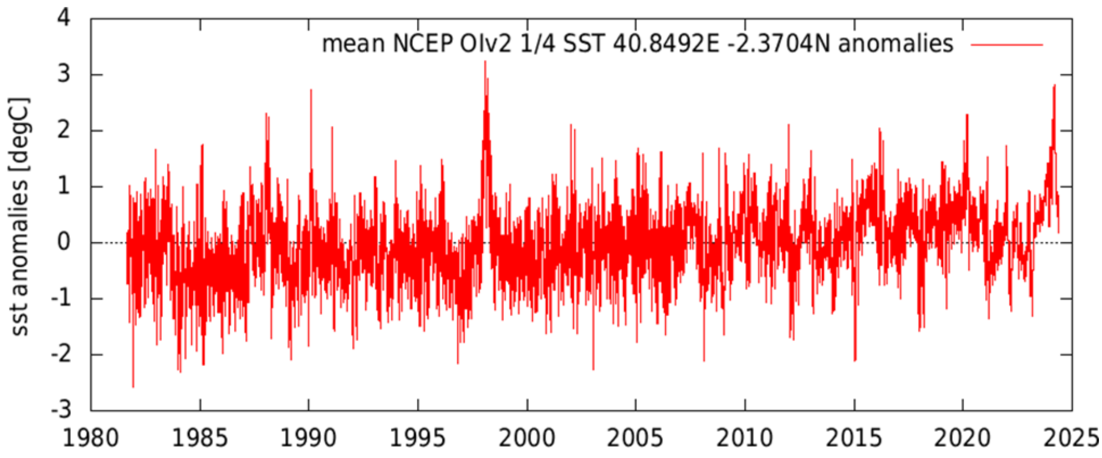


Figure 37: Mean sea surface temperature anomalies analysed from the NOAA/NCDC

Analysis of seasonal or monthly sea surface temperature variation shows colder waters during the period of late March through to May, while hot months are usually during August and January (Fig. 38).

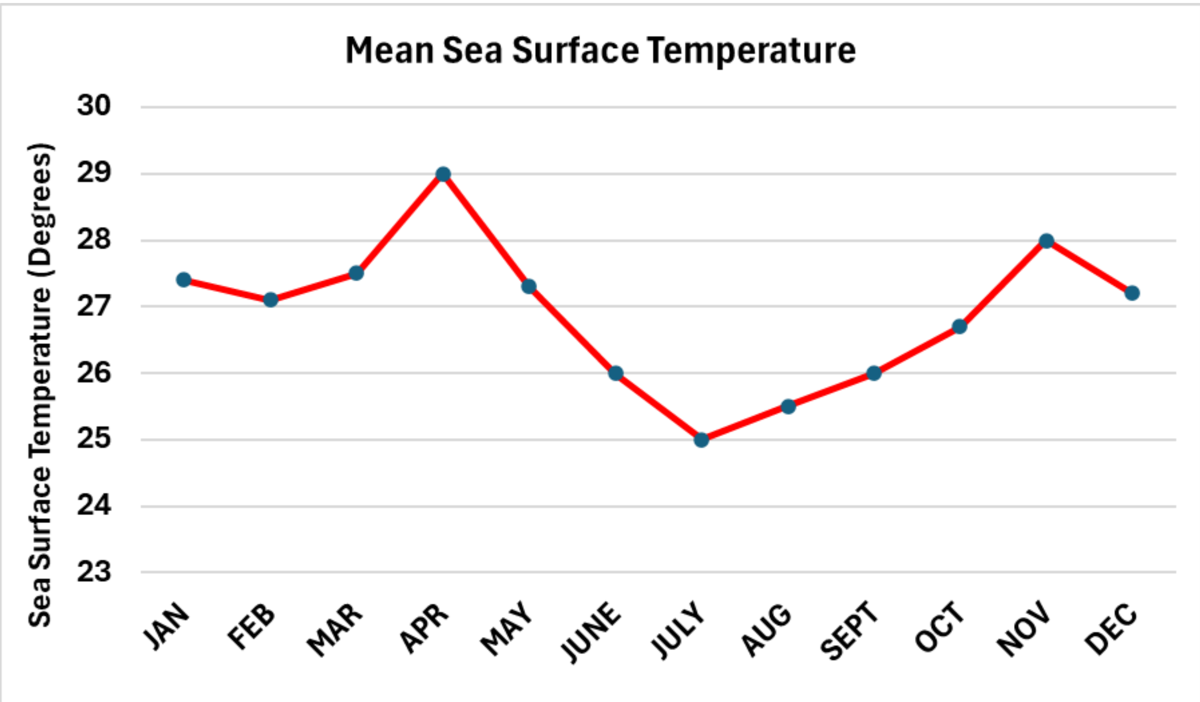


Figure 38: Seasonal variation in sea surface temperature within one year cycle

If warming continues unabated and sea surface temperatures continue to rise, the ability of many marine organisms to adapt may be compromised. This may eventually result in collapse of marine ecosystems and the extinction of numerous marine species. Impacts include repeated mass coral bleaching events in East Africa and the poleward migration of marine life from their original habitats, leading to lost livelihoods for African fishers.

Drought (SPEIs)

Drought and extreme wet hazards were inferred from the Standard Precipitation and Evapotranspiration Indices (SPEI). Droughts are consequences of extreme and persistent temperatures and manifested in the lack of precipitation in a region for a prolonged period. Drought can severely affect the growth of mangrove plans and often lead to stunted growth. In a typical restoration planning process, the cycles of drought and the intensities need to be considered to ensure restoration efforts are planned during favourable seasons. In this section, representative SPEI data for Lamu County was downscaled in comma separated form (csv) from a global database available at SPEI geoportal. SPEI data values above zero were assumed as indicative of flood extremes, while negative values were assumed to represent extreme drought events. This is in line with various research findings such as Bachmair *et al.,* (2018), which also supports that SPEI variates can be used to represent periods of extreme floods and droughts. Lamu has experienced droughts and extreme wetness in certain time, as evidenced by cyclic behaviour with peaks and troughs over the period 1961 to 2022. The 12 months with the lowest SPI values were in the years 1961, 1971, 984, 1988, 2001, 2005. Extreme droughts occurred in 1984, 1986, 1993, 1997, 1999, 2000, 2003, 2004, 2005, 2007, 2008, 2009, 2010, 2012, and 2013. Generally, there has been an increased cycle of droughts, and increasing intensity, but floods have also shown increasing trends lately.

Drought is an indicator of the amount of moisture available or lacking for optimal plant growth. Generally, the drought conditions described by the moisture stress index are likely to get worse for the southern Lamu ecosystem. Restoration interventions must focus on drought resilient practices such as planting tolerant species of mangroves.

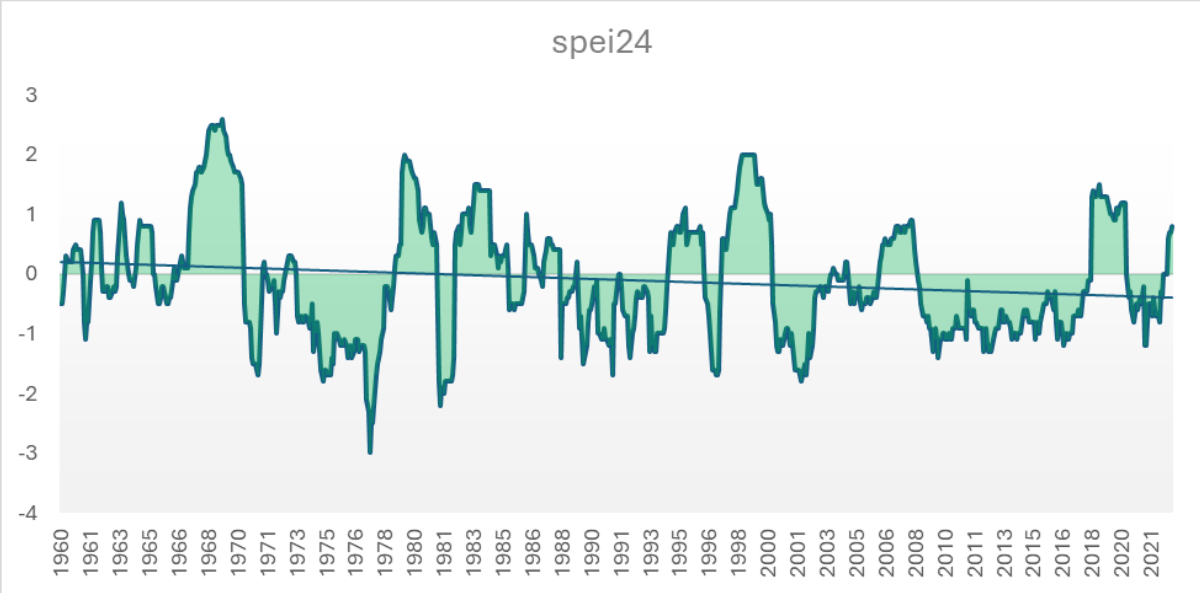
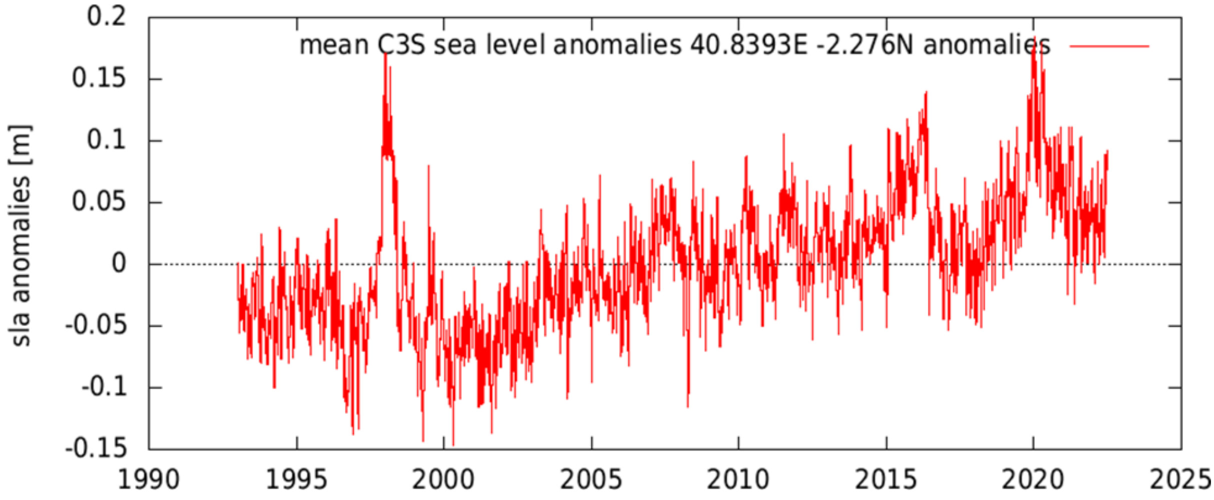


Figure 39: A typical plot illustrating the SPEI trends based on 24-months scale

Sea Level Rise

The rising sea level presents an impeccable challenge to mangroves ecosystems and general livelihoods of communities living along coastal areas, and Lamu in particular being the only county where mangrove harvesting is permitted. Mangroves have a unique tidal range niche within which they extract maximum survival benefits. This niche allows for daily and often monthly cycle of washing and recession of saltwater creating an environment that the Mangroves adapt to. When the sea level rise, this tidal balance is affected, and this is likely to disrupt the ecosystem's functioning.

Moreover, the rising sea levels may lead to damage and destruction of coastal infrastructure including ship docking ports and may lead to even more acute water salinity imbalances due to freshwater-saline water mixing imbalances. Sea level rise could also destroy valuable shorelines teeming with resorts, water sports facilities, beaches, attraction sites and marine parks leading to significant economic losses amounting to hundreds of billion shillings since this area are considered tourist locations. Figure 40 shows the sea level rise baseline trends for the Lamu southern Swamp using Matondoni beach as the base station. This has been done for baseline (1990-2025 and projected 2020-2100.



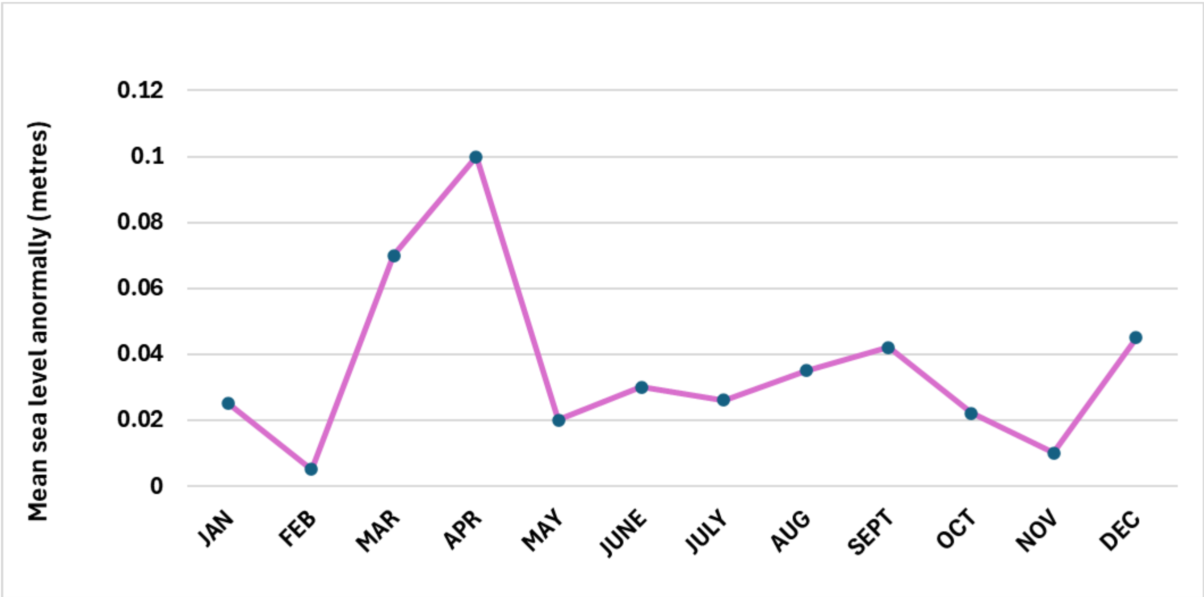


Figure 40: Trends in sea level rise over historical and future projections as well as the seasonal sea level anomalies

Projected Sea Level Rise

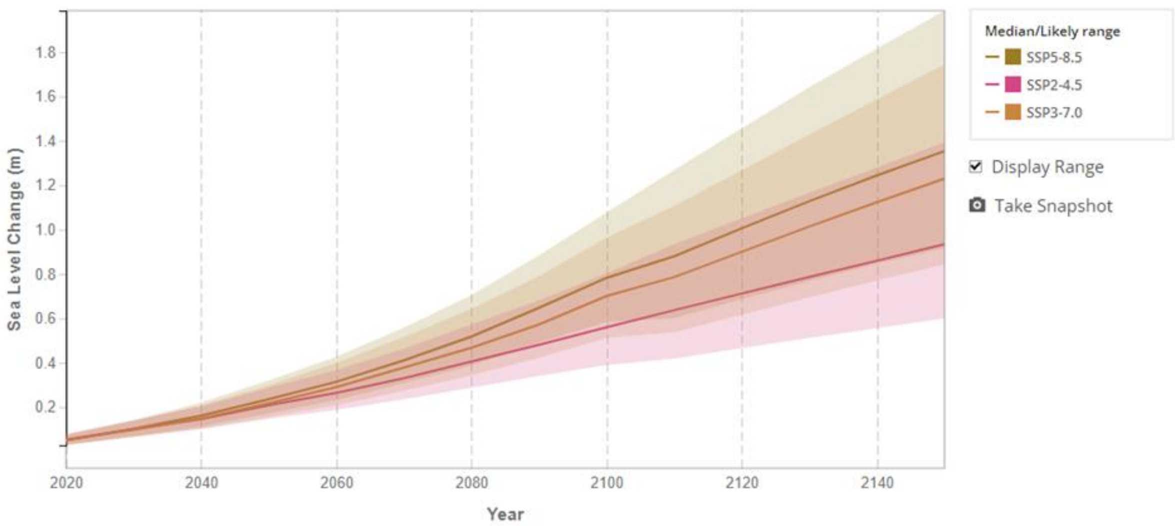


Figure 41: Historical and projected seas level rise in metres under different future climate scenarios (analysed from IPCC climate data portal).

7.2 Simulation of Restoration Scenarios

Data Processing

The following datasets were utilised the simulation of restoration scenarios; (1) a point data layer representing degraded mangrove areas with attributes detailing the degradation level (high, moderate, low), threats, and area in hectares, (2) mangrove extent layer, and (3) above-ground carbon stock raster layer. The point data was converted into polygons representing degraded areas to facilitate spatial analysis, and all spatial analyses were conducted in ArcGIS Pro (version 3.0.0; Esri, 2024). This was done using the Buffer tool in ArcGIS Pro, which generated polygons around each point based on the calculated area (in hectares) provided in the attributes. The buffer radius “r” was calculated using the formula, ensuring that each polygon accurately reflected the degraded area.

The created polygons were then clipped to the mangrove extent using the Clip tool, limiting the analysis to areas of degraded mangrove forests. This step ensured that all restoration scenarios were focused exclusively on existing or potential mangrove vegetated areas (Kairo et al., 2008). The degradation attributes (e.g., degradation level and causes) were transferred to the new polygons via a Spatial Join to ensure consistency across all data layers (Bosire et al., 2008).

7.2.1 Approach to Land Use and Land Cover Assessment

The analysis was based on the 2023 Sentinel-2 satellite imagery. A cloud-free image covering the entire Lamu southern swamp mangroves and that accurately represented the land cover was acquired (European Space Agency, 2023). The image underwent processing through atmospheric correction, georeferencing, and noise reduction to ensure accuracy in the subsequent classification process. Supervised classification was employed to categorise the land cover into distinct classes (Lillesand et al, 2015).

The land cover was classified into six major categories: water (ocean), mangrove, shrubs and scattered trees, deposited sand, built area, and bare ground. Each class was defined based on specific spectral signatures and ground-truth data, ensuring a precise and reliable classification. The classification accuracy was validated using a set of randomly selected samples not used in the training process to ensure an unbiased assessment of the classification accuracy (Congalton & Green, 2019).

7.2.2 Restoration Scenarios Applied

Three restoration scenarios were developed to estimate potential carbon sequestration benefits and degradation recovery:

1. Natural Regeneration: Assumes natural regeneration occurs in low and moderate degradation areas, with partial recovery in high degradation areas. A 50% recovery rate was assigned for low and moderate degradation based on literature (Bosire et al., 2008; Kauffman & Donato, 2012).
2. Active Planting: Assumes active planting in high degradation areas with natural regeneration in moderate and low degradation zones. The recovery rate for high degradation areas was set at 80%, based on restoration case studies (Kairo et al., 2008).
3. Combined Approach: Integrates ecological engineering in high degradation areas, active planting in moderate areas, and natural regeneration in low degradation areas. Recovery rates of 70%, 65%, and 50% were used for high, moderate, and low degradation areas, respectively (Mencuccini et al., 2012).

For each scenario, Raster Calculator tool was used to apply the relevant recovery percentages to the above-ground carbon raster and to the mangrove cover extent. The resulting raster layers represented the potential carbon sequestration and mangrove cover extent recovery under each scenario, allowing us to compare outcomes (Spalding et al., 2010).

7.2.3 Degraded Mangrove Areas in the Lamu Southern Swamp

Figure 42 below shows the analysis outcomes of the locations considered moderate or highly degraded within the southern swamp. Some of these areas have also been identified by the local community forest groups for various restoration programs discussed later in the section.

The following locations were considered severely degraded; Kwa hemedi, Mtosimba, Shakani 2, 23AC, Kitangani, Kwa bwana kombo A, 21A, Wanga 7A, 23AC; While the following are considered moderately degraded namely, Kwa wanga,Ngoi, 18A, Wanga 7B, Bandarini, Mea2, Mea, Kwa Wanga, Bwanakweli, 23AA, Milihoi, Kwa Bonea, Manzabe, Simi, Kitoto, Kirara, Kirara ndogo, Kijuni, Kwa soloma, Banda yamchu, Majeo, Shakani 1, Shongoni.

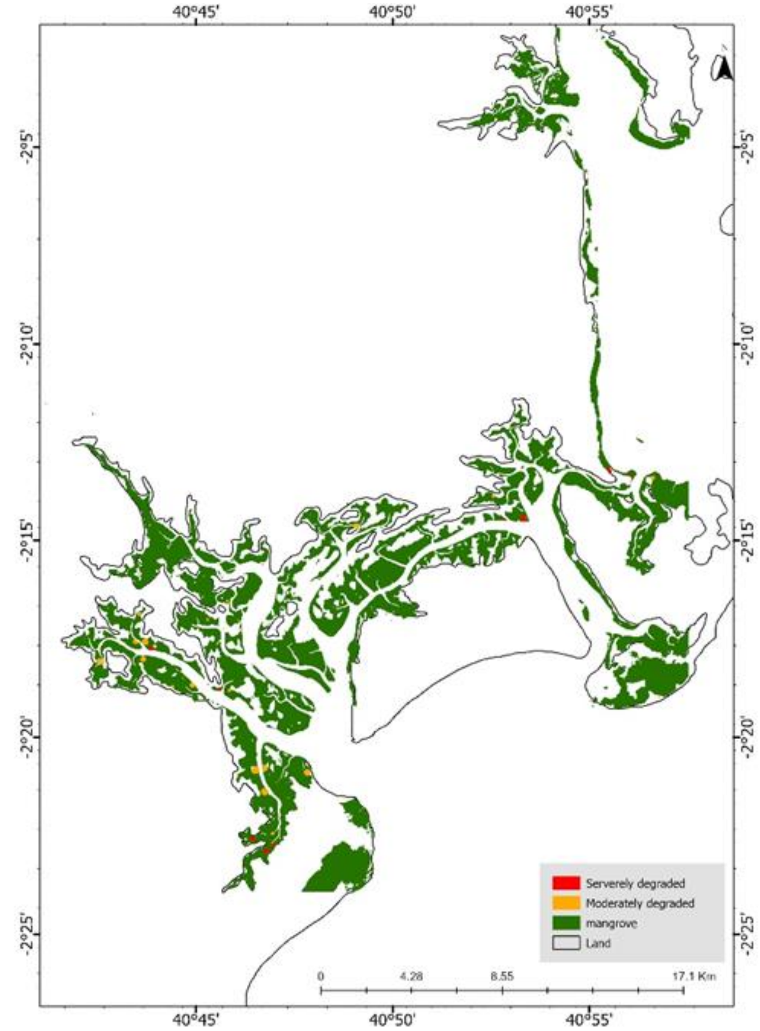


Figure 42: Degradation extent in the Lamu Southern Swamp mangroves

A ground truthing exercise to confirm actual mangrove degradation was undertaken and some of the findings revealed existential mangrove degradation within various locations of the southern swamp. Some of the degraded areas are hidden within the mangrove forest and unnoticeable from the popular water routes, revealing the necessity and need to advocate and adopt better aerial surveillance and air motoring systems to see the extent of degradation.

Table 15: Sample degradation hotspots observed during ground truthing in Lamu

Examples of degradation and restoration efforts in the Lamu Southern Swamp	**Description**
	Mashundwani This is an area tucked deep in the forest and off common waterways The area has experienced progressive degradation since 2017 that resulting in over 10 acres of degradation.
 	Njia ya Ndovu – Kililana The area has experienced human induced degradation owing to the migration of people into the area on the premise of LAPSET transport corridors anticipated displacement and compensation. To enhance their survival, the new settlers cleared vegetation and opened the area. The tree trunks are a sign of the effects of degradation. About 5 acres has been degraded. The standing water has often been a hindrance to the emergence and survival of new seedlings for emerging mangroves.
	Manda Airport Bay According to the local community, this area was formerly covered by dense mangrove forest. This was cleared by a private developer in the area with the prospect of facility development. The clearance was realised to have occurred in the past 6 months.

7.3 Implications of Sea level rise

Mangroves are sensitive to sea level rise and may completely be inhibited by extreme sea level rise. Sea level affects coastal flooding and extent of root submergence of mangroves; however mangroves have specific ranges within which they optimally grow. Some studies like Saintilan et al., (2020) have shown that mangroves have an upper threshold of 7 millimetres per year is the maximum rate of sea level rise associated with mangrove vertical development, beyond which the ecosystem fails to keep up with the change. Other studies such as Gilman et al., (2008) emphasises that Sea level rise will result in increased flooding and potential redistribution of mangrove species which speak to the fact that mangroves may shift habitats as sea level rise dynamics change. There are indications that Mangroves improved their adaptation to sea level rise by moving inward. If the rate of sea level rise is greater than the mangroves accretion rate, then mangroves are pressed to retreat landward so that they can maintain their preferred hydroperiods (i.e. period, frequency and depth of inundation and salinity). But the success of the mangroves' landward migration depends on various conditions such as the ability of individual species to colonise new habitats at required rates (relative to sea level rise), the presence of barriers (mostly man-made such as seawalls, shoreline structures and roads) and the slope of the adjacent land Gilman et al., 2008). In yet other studies such as Sasmito et al., (2016) some evidence shows that sea level may affect tree root growth and the accumulation of sediments from rivers and oceans, processes which may affect Mangroves ability to maintain their forest floor elevation relative to sea level; this process is often referred to as surface elevation change (SEC). However, considering the projected acceleration of the rate of sea level rise, as well as modifications made to coastal environments that impede their ability to respond, it is unclear how mangrove forests will respond to future conditions.

It is therefore important at the point of restoration planning to assess the tidal height and the sea level anomalies to establish the extent of regular water and dewatering caused by ocean tides would be considered to protect new seedlings from growing under optimal conditions.

This report emphasises enhanced precaution on the effects of sea level on present mangrove ecosystems, but also provides opportunities for breeding and planting mangrove species with enhanced sea level adaptation regimes.

7.4 Land Use Land Cover Analysis

7.4.1 Land Use Land Cover and Respective Soil Carbon Assessment

The assessment identified six major land cover categories: mangroves, shrubs, deposited sand, built area, bare ground, and water (ocean). The mangroves, as the focal ecosystem, covered the most significant area of approximately 11,101 hectares, indicative of their extensive distribution across the swamp area as illustrated in Fig. 42

Shrubs and scattered trees occupied a total of 8,163 hectares, reflecting the presence of secondary vegetation types that complement the mangrove ecosystems and contribute to the area's biodiversity. Bare ground, which could be either exposed soil or minimally vegetated areas, constituted the largest land cover type, with a vast expanse of 76,620 hectares. This might be attributed to the swamp's natural soil deposition patterns, low-lying geomorphology, and potential anthropogenic impacts such as deforestation.

Developed areas, which included human settlements and infrastructure, spanned 3,041 hectares. This signifies the human footprint within the swamp region and the interaction between natural habitats and urbanisation. Deposited sand areas covered 667 hectares, representing the dynamic geomorphological processes along the coastal line and potentially areas of sediment deposition influenced by oceanic and fluvial activities.

The classification results provide a comprehensive overview of the current state of land cover in the Lamu Southern swamp area, offering crucial insights for ecological management, conservation efforts, and future land use planning clearly depicted in table1. The precise delineation of land cover types, as illustrated in the map, underscores the diverse and complex nature of the region's landscape, providing a baseline for monitoring environmental changes and human impact over time.

7.5 Assessment of Carbon Stock

Soil carbon stock analysis within the Lamu Southern swamp mangrove area was performed using gridded global soil information from SoilGrids. Data comprising mean carbon stock values (Data source, KMFRI), was reclassified in ArcGIS Pro, and spatial analysis conducted to calculate the mean stocks per land cover type. The results indicated variable soil carbon stocks across different land cover types. Online carbon databases were not used as prescribed in the TOR due to the coarse resolution.

7.5.1 Mean Soil Carbon of the Mangroves of Lamu Southern Swamp

The mean soil carbon stock for the mangrove areas was determined to be the lowest among the assessed land cover types, with a value of 17.9 t ha-1. This value contrasts with the higher stocks found in areas covered by shrubs, which had the highest mean soil carbon stock of 41.008 t ha-1. Bare ground and developed areas exhibited similar soil carbon stocks of 37.68 t t ha-1 and 37.62 t ha-1, respectively, which suggests that human land development may not significantly alter the mean carbon stock in these regions. Deposited sand areas showed a slightly lower mean carbon stock of 34.7 t ha-1, reflecting the influence of soil texture and composition on carbon storage.

The spatial distribution map of soil carbon stocks revealed a heterogeneous distribution of carbon throughout the swamp, with ranges from 0 to 67 t ha-1. The highest carbon stock values (48.001 - 67 t ha-1) were scattered throughout the swamp, indicating pockets of high carbon accumulation. In contrast, areas with the lowest carbon stocks (0.001 - 0 t ha-1) appeared to be more widespread, possibly correlating with regions of lower soil organic content or higher degradation.

These findings underscore the complex interplay between land cover types and soil carbon storage within the Lamu Southern Swamp. The assessment provides critical insights for conservation efforts, indicating areas where carbon storage is maximised and where restoration or protection efforts may be prioritised to enhance carbon sequestration in the context of climate change mitigation strategies.

Table 16: Land cover and land use types by area in hectares and mean soil carbon stocks

Land cover	Area (ha)	Mean soil carbon stock
Deposited sand	667	34.7
Developed area	3,041	37.62
Bare ground	76,620	37.68
Shrubs	8,163	41.008
Mangrove	11,101	17.9

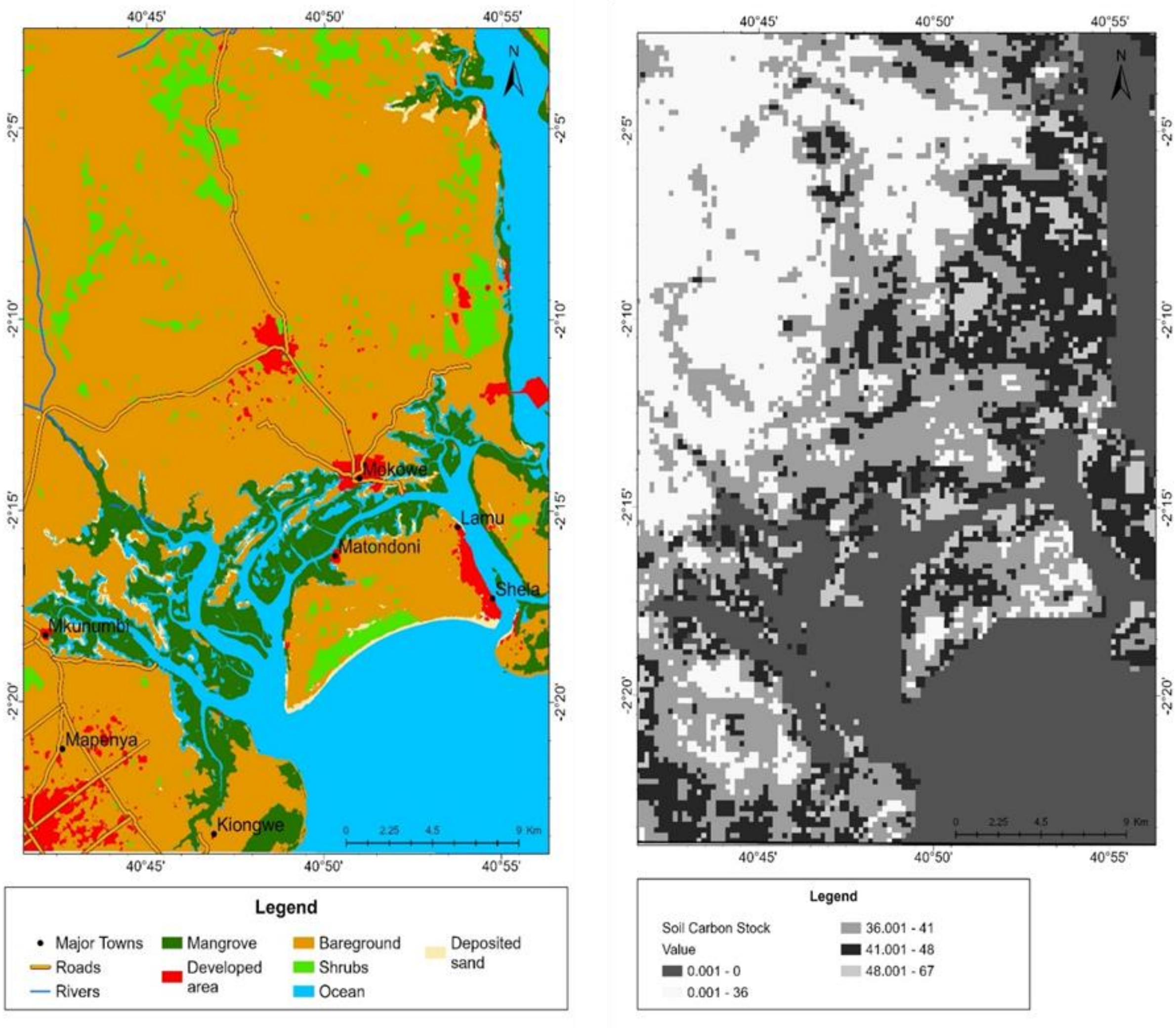


Figure 43: Land use types and categories identified from satellite analysis data for the Lamu Southern swamp

7.6 Development of Restoration Scenarios for the Lamu Southern Swamp

In the light of the United Nations declaration of 2021-2030 as the Decade of Ecological Restoration (Teutli-Hernández *et al.*, 2020), restoration of the degraded mangrove ecosystems of the southern Lamu swamp ecosystem is crucial to this research study, especially considering the levels of degradation already reported. It is reiterated that ecological restoration of mangrove swamps is a Nature-based Solution (NbS) that allows addressing social challenges such as climate change mitigation, recovering services for human well-being, and conserving biodiversity. In Table 17 below, the report highlights some important restoration programs already observed to be taking place in the southern swamp especially through the community forest groups. Already the majority of the CFA groups are engaged in ecological programs including mangrove nurseries for reforestation and afforestation, replanting and community sensitization activities.

The study proposes three main approaches and scenarios of restoration based on the already adopted restoration approaches applied in the Lamu southern swamp and highlighted in the methodology, these include; **natural regeneration** which assumes natural regeneration occurs in low and moderate degradation areas, with partial recovery in high degradation areas, **active planting** which assumes active planting in high degradation areas with natural regeneration in moderate and low degradation zones, and finally **combined approach** which integrates ecological engineering in high degradation areas, active planting in moderate areas, and natural regeneration in low degradation areas. Figure 44 and Table 18 highlight the three restoration scenarios modelled for the various sites experiencing moderate to severe degradation in the Lamu Southern swamp.

The statistics present the recovery rates in terms of hectares restored and amount of carbon stock regained by such a scenario. The severely degraded areas, due to the extent of loss, may not be potential for natural regeneration, as such the study modelled an active planting scenario only. However, for the moderately degraded, some aspects of natural regeneration may be allowed, allowing active planting for maximum combined benefits. Our study revealed that, if adopted, the proposed restoration scenario is likely to realise decline in the amount of degraded area from the present rate of change about 62.53ha to about 31.3 ha, 50.3ha, and 40.7 ha respectively for scenarios 1, 2 and scenario 3. On the other hand, carbon indicates slight increase by about 2% from the present amount of 602 Mg C/ha from the moderately degraded areas.

Table 17: Ongoing restoration efforts in Lamu Southern swamp

Examples of degradation and restoration efforts in the Lamu Southern Swamp	**Description**
	Matondoni village The area was originally called "*mtondo*" meaning a place of many trees. Over the years, there has been notable decline in mangrove cover in the matondoni coastal area largely due to cutting and settlement practices. The community has observed a growing decline in fish stock. Few community members, of mostly women groups, started mangrove nursery raising programs with the help of partners. Presently they have 15 small women groups. The nursery has been able to support the reafforestation programs in the area.
	Mashundwani The area has experienced progressive since 2017 that has resulted in over 10 acres of degradation. Since 2020 there has been assisted planting There are about 800 seedlings planted in the tree nursery. In one single replanting activity 2024, over 1000 mangroves were replanted with the support of partners
	Njia Ndovu – Kililana This has been a site of multiple interventions in restorations, the existing CFA has made it site of their annual replanting drive. The community reported to have planted over 10,000 seedlings in the past 2 years. There was more success in reestablishing seedlings in the open degraded areas than in areas with stagnant waters.

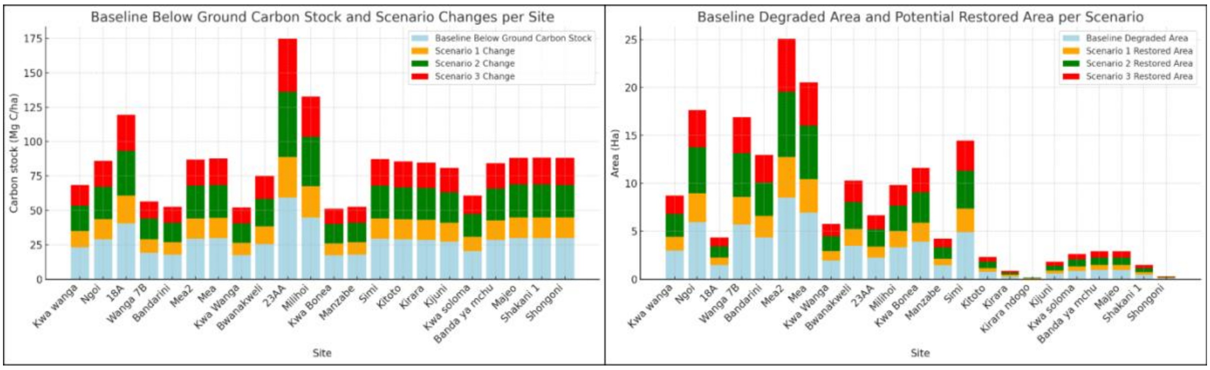


Figure 44: Projected area and carbon change based on mangrove restoration Scenarios for moderately degraded areas

Table 18: Projected change based on mangrove restoration Scenarios for Severely degraded areas

Severely degraded sites	Area	carbon	Scn_2_Area	Scn_2_carbon
Kwa hemedi	3.013136	29.85213	2.410508	23.881704
Mtosimba	3.525537	29.91706	2.820429	23.933648
Shakani 2	1.492887	29.92288	1.19431	23.938304
23AC	2.553425	47.78355	2.04274	38.22684
Kitangani	0.807289		0.645831	
Kwa bwana kombo A	1.284192	28.63408	1.027353	22.907264
21A	4.819173	36.23352	3.855338	28.986816
Wanga 7A	3.414032	18.79192	2.731225	15.033536
23AC	1.304516	56.90543	1.043612	45.524344

7.7 Potential Mitigation Benefits of Mangroves Restoration

A. Mangroves are known to be one of the most efficient ecosystems in the world when it comes to removing carbon dioxide from the atmosphere. They achieve this because of the way they grow and function. The roots of mangrove trees are submerged in water, creating an oxygen-poor environment that slows the decomposition of organic matter. This leads to the buildup of organic carbon in the soil, which undisturbed can remain sequestered for hundreds of years.

B. Mangrove trees also have the ability to store carbon in their biomass. They grow faster than most other trees and can store carbon at a rate of up to four times that of a tropical rainforest. This is because mangroves have a high leaf area index, which means they have a lot of leaves relative to their size. This allows them to capture more sunlight and grow faster, which in turn leads to greater carbon storage.
C. Mangroves can sequester up to ten times more carbon per hectare than other terrestrial ecosystems, since mangroves have higher rates of organic matter production and slow decomposition, which contributes to the accumulation of carbon in the soil and vegetation
D. Mangroves are also more efficient than other coastal ecosystems such as seagrass meadows and salt marshes. While these ecosystems are important carbon sinks, they sequester less carbon than mangroves because they have lower biomass and slower rates of growth. Mangroves are estimated to store up to four times more carbon per hectare than other types of coastal wetlands, such as salt marshes and seagrass meadows.

7.8 Enabling Environment for Mangrove Restoration

A. **Site selection:** Choosing the right location for mangrove restoration is crucial. The site needs to have the right environmental conditions to support mangroves, including appropriate soil types, adequate water flow, and appropriate levels of salinity.
B. **Community Involvement**: Involve the local community from the beginning of the project, during the implementation stage, and in evaluation and completion activities
C. **Cost:** Mangrove restoration is undoubtedly an expensive process, as it involves many steps, including site preparation, tree planting or purchases from Nurseries, and monitoring. Additionally, the cost of maintaining the restored mangrove forest over time can also be high.
D. **Human interference**: Mangrove ecosystems are under constant threat from human activities such as logging, agriculture, and urbanisation. These activities can cause damage to mangrove forests and make restoration efforts more difficult. Efficient deterrence to human interference is therefore key in mangroves restoration programs
E. **Seedling survival**: While planting seeds or seedlings is a key step in mangrove restoration, ensuring their survival can be challenging. Seeds and seedlings may be vulnerable to predators or adverse environmental conditions, such as flooding, saltwater intrusion, and storms.
F. **Long-term monitoring and maintenance**: Mangrove restoration is a long-term process that requires ongoing monitoring and maintenance. Regular monitoring is needed to assess the success of the restoration effort and adjust as needed.
G. **Knowledge and skills**: There is still much to learn about the ecology and biology of mangroves, and their restoration. The complexity of the interactions between different species of mangroves, as well as between mangroves and other ecosystems, makes it difficult to predict the outcomes of restoration efforts.

7.9 Conclusion

Climate change is likely to have a substantial impact on mangrove ecosystems, through processes including sea level rise, changing ocean currents, increased storminess, increased temperature, changes in precipitation and increased CO_2.

Sea-level rise is a major threat to mangrove ecosystems because mangroves are sensitive to changes in inundation duration and frequency, as well as salinity levels that exceed a species-specific physiological threshold of tolerance. Increases in flooding duration can lead to plant death at the seaward mangrove margins and shifts in species composition can reduce productivity and ecosystem services. Coastal flooding is expected to increase in the future as global sea levels continue to rise.

Likewise, storms can significantly influence mangroves productivity and health. Intense storm events can have both destructive and constructive impacts on mangrove ecosystems. The intensity of storms in a particular coastal zone is likely to be influenced by mangrove position in relation to storm track, storm characteristics (wind velocity, storm intensity radius of maximum wind) and degree of exposure as well as occurrence of storm in relation to high tide, particularly in meso- and macro- tidal areas.

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