AN ASSESSMENT OF THE EFFECTIVENESS OF MANGROVE RESTORATION PROJECTS ALONG THE KENYAN COAST

BY

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DECLARATION

I ABEL KIPRONO do hereby declare that this is my original work and that it has neither been presented nor submitted for a degree in any other University. No part of this thesis may be reproduced without the prior written permission of the author and/or the University of Nairobi.

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DEDICATION

I dedicate this work to my dad, Samson Choge who introduced me to nature conservation through tree planting at my tender age in my home village (Chemagal), Bonjoge location in Nandi South sub-county. This sparkled and ignited my desire and passion for nature conservation particularly, forest landscape conservation and restoration.

In memory of the late Alfred Obinga,

Mangrove Extension officer, KMFRI

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LIST OF ACRONYMS

ANOVA	Analysis of Variance
CFA	Community Forest Association
CO_2	Carbon (IV) oxide
COMENSUM	Community Environmental Sustainable Mariculture
COP	Conference of Parties
DBH	Diameter at Breast Height
EMR	Ecosystem Mangrove Restoration
FAO	Food and Agricultural Organization of the United Nations
GHGs	Green House Gases
GIS	Geographical Information System
GMA	Global Mangrove Alliance
GoK	Government of Kenya
GPS	Global Positioning System
ha	Hectares
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IGA	Income Generation Activities
KFS	Kenya Forest Service
KMFRI	Kenya Marine and Fisheries Research Institute
KEFRI	Kenya Forestry Research Institute
KII	Key Informant Interview
LRS	Linear Regeneration Sampling

LTDCT	Lower Tana Delta Conservation Trust
MAI	Mean Annual Increment
MEA	Multilateral Environmental Agreement
m	metre
PMCC	Pate Marine Community Conservancy
NCCAP	National Climate Change Action Plan
NDCs	Nationally Determined Contributions
RC	Regeneration Class
SDG	Sustainable Development Goals
SD	Standard Deviation
SER	Society for Ecological Restoration
SERI	Society for Ecological Restoration International
SLR	Sea Level Rise
SOMN	Save Our Mangroves Now
SPSS	Statistical Package for Social Sciences
t	tonnes
TNC	The Nature Conservancy
UNEP	United Nations Environmental Programme
UNGA	United Nations General Assembly
VAJIKI	Vanga Jimbo Kiwegu
WIO	Western Indian Ocean
WIOMSA	Western Indian Ocean Marine Science Association

ABSTRACT

Kenya has made several initiatives to support restoration of lost and degraded mangrove forest areas along the coast. The initiatives have involved both mangrove reforestation and natural regeneration. This study investigated the effectiveness and the outcome of mangrove restoration programs along the Kenyan coast. It mapped the location of the project sites, areal extent, and evaluated success indicators, underlying challenges, and community perception towards mangrove restoration. The study adopted vegetation and social survey methods. Square plots of 10 x 10m were randomly established on reforested areas in order to assess the growth performance of replanted mangroves. Purposive sampling was used in questionnaire administration for social surveys. Arc GIS software was used to develop a geolocation map; whilst MINITAB software and Shannon Wiener diversity index (H) formula were used for statistical and diversity analysis, respectively. Statistical Package for Social Sciences (SPSS) software was employed for analysis of social survey data through descriptive statistics. A total of 107 respondents including 7 key informants were interviewed. A total of 19 project areas with a total of 53 replanted sites were surveyed; translating to an estimated area of 93.5 ha of replanted mangroves. *Rhizophora mucronata* and *Ceriops tagal* were the most preferred mangrove species reforestation. The survival rate of surveyed plantations ranged from 0 – 97.8% (mean 55.4±31.2%). Sites with high survival rates (>80%) included Mikindani, Jomvu Kuu, and Pate, while some sites in Mwache, Kiwegu, Jimbo recorded more than 90% mortality. Failure of restoration success was attributed to species mismatch, change in site conditions as well as biophysical disturbances while successes saw the application of best practices and good governance. Stocking rates of 5 – 24-year-old mangrove plantations ranged from 3575 – 7825 stems/ha; with Mean Annual Increment (MAI) of height, diameter and biomass estimated of

0.34m/yr (range: 0.11 – 0.57m/yr), 0.35cm/yr (range: 0.12 – 0.52cm/yr) and 5.96t/ha/yr (range: 2.02 – 15.67t/ha/yr) respectively. Natural recruitment in reforested areas ranged from 175 – 7150 saplings/ha (mean: 2081 saplings/ha) while the biodiversity index (H) of macrofauna (crabs and mollusks) was between 1.60 – 1.87. Ecological and economic benefits were the main factors that motivated local communities to participate in restoration activities. To ensure future restoration success, this study emphasizes the need to apply principles of ecological mangrove restoration, strengthen stakeholders' participation, incentivize restoration activities as well as promote long-term monitoring of replanted mangrove sites. This will accelerate the achievement of the local and national priorities of the United Nations Decade (2021-2030) on Ecosystem Restoration.

CHAPTER ONE: INTRODUCTION

1.1 Background information

Losses of natural ecosystems through deforestation and other factors are amongst the challenges facing human society and the achievement of sustainable development worldwide (IPBES, 2019). Over the past decades, global efforts have been made to address the underlying issues. These have been evidenced through global policies, declarations, development, and the signing of Multilateral Environmental Agreements (MEAs) aimed at addressing the loss and degradation of natural habitats (Leggett and Carter, 2012). Renewed efforts have been received after the United Nations General Assembly proclaimed 2021-2030 as the Decade on Ecosystem Restoration (hereinafter referred to as the UN Decade) of all ecosystems on earth (UNGA, 2019). The UN Decade focuses on reviving land and restoring degraded landscapes whilst providing nature-based solutions to a wide range of global goals and priorities (UNGA, 2019; Waltham *et al.*, 2020). This Decade becomes more powerful and effective when tied with the Decade of Ocean Science for Sustainable Development (UNGA, 2017).

The UN Decade unites the world towards a common goal: *preventing*, *halting*, and *reversing* the degradation of ecosystems on the planet. It also firms up the Bonn's Challenge goal to revive 350 million hectares of degraded land globally by 2030 and accelerate the achievement of the Paris Agreement (Gichuki *et al.*, 2019). While Africa has committed to restoring 100 million hectares under Bonn's Challenge, Kenya aims to restore an estimate of 5.1 million hectares of degraded land, including mangrove forests by 2030 (Gichu *et al,* 2016). Ecosystem Restoration (ER) is now becoming a global priority (Aronson and Alexander, 2013; UNGA, 2019) whereas mangrove forest has given a cause for conservation optimism to rebuild marine life (Friess *et al.*, 2020; Duarte *et al.*, 2020). However, past mangrove restoration practices have presented mixed results with more failures reported than successful stories around the world (Primavera and Esteban 2008; Worthington and Spalding, 2018). Many restoration projects have failed because the vision is unrealistic in ecological terms, the species planted are inappropriate and the locations are not ideal (Lee *et al.*, 2019; Waltham *et al.*, 2020).

Therefore, it is vitally important to first understand the project attributes that characterize the ecosystems that have been successfully restored (Le *et al.*, 2012). This signifies the ecological recovery, restoration of ecosystem integrity and functionality. However, there exist different criteria used to evaluate the effectiveness of restoration programs (Wortley *et al.*, 2013). The Society of Ecological Restoration International (SERI) developed a key indicator to evaluate the success of a restored ecosystem in reference to the natural community (SER, 2004). These attributes have been placed into three categories, namely vegetation structure, ecological processes, and species diversity (Ruiz-Jaen and Aide 2005a).

In Kenya, trial mangrove reforestation for the restoration of intertidal areas and the transformation of degraded sites into productive forests was initiated in the early 1990s at Gazi bay (Kairo, 1995a, 1995b; Kairo *et al.*, 2001). The initiative involved both direct planting of propagules as well as the use of nursery-raised saplings in designated reforestation areas. These initiatives have, however, yielded low output than expected. Questions then arise; (1) how can we achieve successful mangrove reforestation? (2) what are the indicators of a successful mangrove reforestation program? and (3) what is the role of communities in the achievement of successful mangrove restoration?

Earlier studies in Kenya have mainly focused on the secondary succession of both flora and fauna (Bosire *et al.* 2003, 2004, 2005, 2006), tree growth rates, biomass accumulation, and litter productivity (Kairo *et al.* 2008; Tammoh *et al.,* 2008; Wang'ondu *et al.* 2014) and social-economic impacts of mangrove plantations in Gazi bay (Kairo *et al.,* 2009). While other restoration efforts have been initiated along the Kenyan coast, it is not clear how effective these programs are in achieving the desired goals and objectives. There is a paucity of information regarding growth performance and challenges facing mangrove reforestation programs. This study, therefore, aimed at conducting an extensive assessment of the performance of mangrove restoration initiatives along the Kenya Coast.

1.2 Problem Statement

Mangrove conservation and management in Kenya has not been optimized as compared to their terrestrial counterparts (GoK, 2017a). In the past, the sectoral approach coupled with conflicting policies did not recognize the interconnectedness of ecosystems thus prevented rational utilization of mangrove forests in Kenya (Kairo *et al.,* 2001). Consequently, mangrove forests were over-exploited and degraded at an alarming rate (FAO, 2005; Abuodha and Kairo, 2001; Kirui *et al.,* 2013). Approximately, 18% of mangrove cover was lost between the years 1985 and 2009 (Kirui *et al.,* 2013) while at least 40% of existing mangrove cover is perceived to be in degraded conditions (GoK, 2017a).

To counter this, mangrove restoration initiatives have been increasingly proposed as mechanisms to compensate for the loss and degradation. However, past mangrove reforestation activities in Kenya have yielded low output than expected (Kairo *et al.,* 2001; UNEP Nairobi Convention, 2020). To exacerbate this, the institutions mandated to conserve and manage mangroves have been incapacitated by inadequate technical expertise and financial capacity to support the management practices (UNEP Nairobi Convention, 2020). While most of the studies on replanted mangroves have concentrated at Gazi bay, the sustainability of other mangrove reforestation activities along the Kenyan coast has not been documented. Therefore, there was a need to have an inventory of various mangrove restoration projects in place, understand their nature, challenges, and their modes of operations.

1.3 Research Objectives

1.3.1 Main Objective

To enhance successful mangrove restoration along the Kenyan coast to sustainably supply ecosystem goods and services to human society,

1.3.2 Specific Objectives

1. To determine the area extent, location and choice of mangrove species replanted along the Kenyan coast,
2. To evaluate growth performance and secondary succession in replanted mangroves along the Kenyan coast,
3. To assess community perceptions of mangrove reforestation activities along the Kenyan coast.

1.3.3 Research Questions

1. What are the ongoing mangrove restoration projects, location and type of species planted?
2. What are the indicators of successful mangrove restoration program?
3. What is the role of communities in the achievement of successful mangrove restoration?

1.4 Justification of the study

Deforestation and degradation are among the major challenges that hinder the sustainable mangrove forest management in Kenya. Whilst efforts to restore this ecosystem are gaining momentum, this study is significant to highlight challenges facing mangrove restoration programs in Kenya in order to avoid a repeated cycle of failure. Successful mangrove restoration has high potential to increase the supply of ecosystem goods and services for the benefit of people and nature. These include increased mangrove resource base for shoreline protection and stability, biodiversity conservation, increased fisheries, wood products and creation of job opportunities and income to people. As such, it will accelerate the achievement of priority actions of the National Mangrove Managemnt Plan thus ensure sustainable forest management as well as improvement of community livelihood.

Most importantly, mangrove conservation and restoration provide nature-based solutions for mitigate climate change due to their huge potential to capture and store high amounts of carbon dioxide from the atmosphere thus a pathway to low carbon economy and climate-resilient development as stipulated in the Kenya's National Climate Change Action Plan (GoK, 2018). This could contribute to the achievements of nationally determined contributions (NDCs) to the Paris Agreement as well as meeting global priorities for sustainable development – the 2030 Agenda. Additionally, the successful restoration of mangroves could contribute to the achievement of 10% forest cover (Kenya's Vision 2030) while directly responding to the UN's Decade (2021-2030) clarion call on restoration of degraded ecosystems globally.

1.5 Scope and limitation of the study

The study primarily focused on vegetation recovery after mangrove restoration activities along the Kenyan Coast. While attention has been on replanted mangroves and the growth performance of the species, natural regeneration has been observed in areas where parental trees were left after harvesting. The following parameters were assessed: survival rates, height, diameter and biomass increments, and secondary succession. While success indicators include ecological processes and social-economic impacts, these are not covered in this study. Instead, the study delved into community perception of mangrove restoration practices.

CHAPTER TWO: LITERATURE REVIEW

2.1 Mangrove ecosystem

Mangroves are trees and shrubs that grow in the sheltered intertidal areas of tropical and subtropical coasts of the world (Polidoro *et al.,* 2010; Friess *et al.,* 2019). They are severally described as coastal wetlands, tidal forests growing in brackish and saline tidal waters. Mangrove trees dominate the mangrove ecosystem as primary producers. They interact with associated aquatic fauna, physical and social-ecological systems of the coastal environment (Nagelkerken *et al.,* 2008; Rog *et al.,* 2016). Mangroves are interconnected with other adjacent ecosystems including seagrass and coral reefs through biological, physical, and chemical interactions (Primavera *et al.*, 2019). Their interaction provides ecological functions which support fisheries, feeding grounds, and habitat for large biodiversity (Nagelkerken *et al.,* 2008; Guannel *et al.*, 2016).

Mangrove structure and function vary greatly due to geomorphology, soil substrate, hydrology (tidal regimes), salinity, and temperature (Friess, 2016; Primavera *et al.,* 2019; Ellison, 2019). In response to this, mangroves species have unique adaptations including (crypto) vivipary where seeds mature and germinate on a mother tree to allow quick rooting in harsh environmental conditions (Ellison *et al.,* 2019). They also excrete or accumulate excess salts in their leaves and roots to withstand high saline conditions. Globally, an estimate of 60 - 70 species of mangroves and their associated plants have been classified into 40 genera (Spalding *et al.*, 2010).

2.2 Global status and distribution of mangroves

Globally, all mangroves are restricted to the tropical and subtropical coasts between 32° N and 38° S (Spalding *et al.*, 2010). The latitudinal limits of mangroves are determined by temperature patterns; both sea-surface and air temperatures (Giri *et al.,* 2011). They have a widespread location and are found in 123 countries with an estimated coverage of 13.8 million hectares accounting for only 0.7% cover of the global tropical forests (Spalding *et al.,* 2010; Giri *et al.,* 2011; Bunting *et al.*, 2018). The largest expanse of mangroves is found in Asia with a coverage of 42%; followed by Africa with 20%, Central and North America (15%), Oceania (12%), and South America (11%) (Giri *et al.*, 2011).

In the Western Indian Ocean (WIO) region, mangroves cover an approximate area of 1 million hectares which represents about 5% of the global cover (Bosire *et al.,* 2016). These forests occupy sheltered shorelines, deltas, creeks, bays, and estuaries. Approximately 90% of mangroves in the region are found in four countries, namely Mozambique, Madagascar, Tanzania, and Kenya. The most productive mangroves in the WIO region are found in the deltas of Tana River (Kenya), Zambezi and Limpopo rivers (Mozambique), River Rufiji (Tanzania), and along the west coast of Madagascar at Mahajanga, Nosy be, and Hahavavy. High productivity has been attributed to freshwater and nutrient supply from the hinterland (Bosire *et al.*, 2016).

2.3 Mangrove goods and services

Mangrove forests are highly productive and valued blue carbon ecosystem on earth (Alongi, 2009; Mehvar *et al.,* 2018; Macreadie *et al.,* 2019). Due to new studies, the valuation of mangrove ecosystem services has increased from US$14 000/ha/yr to around US$ 190 000/ha/yr between 1997 and 2011 (De Groot *et al.,* 2012; Costanza *et al.,* 2014). Specifically, mangroves forests provide invaluable ecosystem goods and services at different levels as shown in Table 1 (Ewel *et al.*, 1998; Lee *et al.*, 2014; UNEP, 2014)**.** Past studies have proven that mangrove forests play key roles in coastal protection and stability (McIvor *et al.*, 2012; Spalding *et al.*, 2014), support to coastal fisheries (Walters, 2000; Hutchison *et al.*, 2014), and sustainable provision of wood products (Sillanpaa *et al.*, 2017).

Table 1. Mangrove goods and services at different levels

Local-level	**National level**	**International level**
Timber and firewood	Charcoal production	Education and research
Fodder for animals	Shrimp and crab industries	Preservation of biodiversity
Fisheries	Timber production	Conservation
Protection from storm	Mangrove silviculture	Carbon sequestration
Traditional medicine	Trade	Indicator of climate change
Recreation	Education and research	
Shell collection	Water quality management	
Erosion control	Coastal and estuary protection	

Source: Ewel *et al.*, 1998; Lee *et al.*, 2014

Besides, mangroves capture and store huge stocks of carbon in both above and below ground components; making them among the richest carbon ecosystems on earth (Donato *et al.*, 2011). Most of the carbon in mangroves is stored in the sediments which form part of below-ground components – highly susceptible to a significant release of carbon when disturbed (Fig. 1; Donato *et al.*, 2011; Gress *et al.*, 2017). Globally, carbon sequestration by mangroves is estimated at 31.2 – 34.4 million megagrams of carbon per year (Howard *et al.*, 2017).

These carbon stock risks being emitted back to the atmosphere when mangroves are lost or their land is converted to other land uses (Pendleton *et al.*, 2012; Lovelock *et al.*, 2017; Hamilton and Friess, 2018). For this reason, restoration and conservation of mangroves can be financially incentivized through green payments (Murray *et al.*, 2011; Locatelli *et al.*, 2014) to conserve and protect carbon stocks which makes them strong candidates for inclusion in the country's nationally determined contributions (NDCs) to the Paris Agreement (Howard *et al.*, 2017; Taillardat *et al.*, 2018).

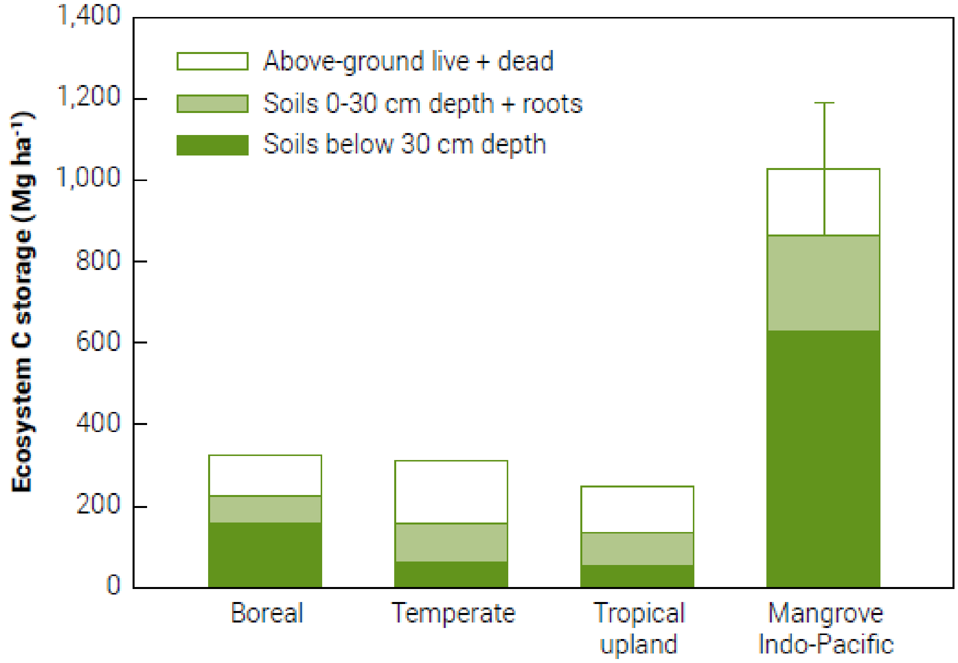

Figure 1: Comparison of mangrove C storage with other ecosystems; Source: Donato et al., 2011.

2.4 Threats to mangrove forests

Causes of mangrove loss and degradation can be divided into human and natural stressors

2.4.1 Human-induced pressures

Mangroves were estimated to occupy 18,100,000 ha worldwide by Spalding *et al.*, (1997), but this global coverage was revised downward to 13,776,000 ha by Giri *et al.*, (2011). Between the 1980s and 1990s, at least 35% of mangrove forest cover was degraded and lost worldwide (Valiela *et al.*, 2001), with losses of up to 80% in some regions (Wolanski *et al.*, 2000; Bosire *et al.*, 2014). Spalding *et al.*, (1997) documented a combined loss of 7.4 million ha in Malaysia, Thailand, Philippines and Vietnam attributed to pond aquaculture. Globally, mangrove loss and degradation can be largely attributed to human population pressure and land-use conversion (Alongi, 2002; Giri *et al.*, 2011). Specific reasons include exploitation for timber and non-timber products, urbanization, aquaculture, and agricultural conversion (Hamilton and Casey, 2016; Thomas *et al.*, 2017; Friess *et al.*, 2019).

Africa lost an estimated 500,000 ha between the years 1980 and 2005 mainly attributed to unsustainable utilization and land-use conversion to other uses (FAO, 2007). A case of the Eastern Cape in South Africa where the whole harvesting of mangroves by adjacent communities has been observed (Rakjaran and Adams 2010) while in Tanzania, plantation agriculture, mariculture, and solar salt pans are the major factors (Nindi *et al.* 2014).

2.4.2 Natural induced stressors

Occurrences of extreme events (tsunamis, cyclones, and floods) have caused massive loss and destruction of mangroves in disparate regions around the world including Indonesia, Sri-Lanka, Brazil, and Mozambique just to mention a few (Adger *et al.,* 2005; Macamo *et al.,* 2016; Sippo *et al.,* 2018; Servino *et al.,* 2018). For instance, in the Save delta in Mozambique, almost half of the mangroves were reported degraded and lost due to sedimentation associated with cyclones and extreme precipitation (Massuanganhe *et al.* 2015) while severe impacts have been predicted especially in the island states (Charrua *et al.,* 2020).

Climate change also threatens the remaining mangrove areas mainly through rising sea levels and increasing sedimentation and aridity (Saintilan *et al.,* 2014, 2019, 2020). Global warming of 1.5^0 is projected to drive loss and damage to coastal ecosystems including mangrove forests (IPCC, 2019). In response to rising sea levels, four scenarios are likely to occur. These include; no change in mangrove position, mangrove margins transgress seaward, mangrove margins transgress landward, and mangroves drown when their expansion corridor is blocked as a result of coastal squeeze inherent to coastal development (Gilmal *et al.*, 2008; Lovelock *et al.*, 2015; Lovelock, 2020).

2.5 Mangroves in Kenya

Mangrove forests cover an approximate area of 61,271 hectares; representing 3% of the country's gazetted forests or 1% area of the country's landmass. Lamu county accounts for 61% of the mangroves in Kenya; followed by Kwale, (14%), Kilifi, (14%), Mombasa, (6%), and Kilifi (5%) (Table 2, GoK, 2017a). These forests provide invaluable goods and services that are of ecological and social-economic importance to coastal communities. Tangible benefits of mangroves include harvestable wood products that are used for building poles and energy (Abuodhaa and Kairo, 2001; Okello *et al.*, 2019; Owuor *et al.*, 2019). Mangroves also provide habitation for fish and other wildlife and protect shorelines against erosion. In addition, the mangroves of Kenya capture and store huge stocks of carbon per unit area, 10 times more than their terrestrial forests (GoK, 2017a).

Table 2. Mangrove forest distribution along the Kenyan Coast

County	Area(ha)	Percentage cover (%)
Lamu	37,350	61
Tana River	3,260	5
Kilifi	8,536	14
Mombasa	3,771	6
Kwale	8,354	14
Total	61, 271	100

Source: GoK, 2017a

2.5.1 Threats to mangroves in Kenya

Mangrove forests in Kenya are threatened by both anthropogenic and natural stressors. Between 1985 and 2009, approximately 18% of mangroves were lost; translating to 450 ha per year (Kirui *et a.*, 2013) while 40% of the existing mangrove stands are perceived to be in degraded condition

(GoK, 2017a). Human-induced factors range from overexploitation for wood products (firewood, poles, timber), pollution, and land-use conversion for aquaculture, saltpans, and infrastructural development (Abuodha and Kairo, 2001; GoK, 2017a; Hamza *et al.,* 2020). The worst scenarios are in peri-urban areas where illegal wood extraction and impacts from land use-based activities have claimed up to 86% of mangroves of Tudor in Mombasa (Kitheka *et al.,* 2002; Bosire *et al.,* 2014).

Furthermore, development projects along the coast are likely to increase sediment loading as well as solid waste dumping to the marine environment thus affecting the healthy ecosystem of mangroves. This is in addition to pollution from municipal wastes and oil spills (GoK, 2017a). Damming and diversion of rivers lead to hydrological changes. For instance in Gazi Bay, damming of River Mkurumudzi is likely to impact negatively on mangroves of Gazi Bay.

On the other hand, mangroves seem not to have suffered much from natural-induced stressors. Few cases are reported where mangroves died due to massive sedimentation and a prolonged period of flooding in Mwache, after the 1997 *Elnino* (Kitheka *et al.,* 2002). Other reported stressors include pest infestation which has targeted single mangrove species, *Sonneratia alba* (Jenoh *et al.,* 2016, 2019). Additionally, climate change threatens the survival of mangrove forests on low-lying mangrove areas due to sea-level rise and flooding (SLR) (GoK, 2017a).

2.5.2 Conservation and Management Interventions

For a long time, mangrove management had not been optimized in Kenya as compared to their terrestrial counterparts. This led to rampant loss and degradation of mangrove forests along the Kenyan coast (Abuaodha and Kairo, 2001; Kirui *et al.,* 2013). In line with Forest Act (2016), the government developed the National Mangrove Ecosystem Management Plan (2017-2027) to guide the conservation and management of mangroves in the Country (GoK, 2017a). More importantly, it provides a roadmap towards sustainable utilization of mangroves for enhanced livelihoods. The plan also advocates for collaboration and participation of various stakeholders and sectors within the landscape hence taking cognizance of other existing policies related to land and land use, agriculture, fisheries, wildlife among others.

For effective conservation and management of mangroves in Kenya, the plan has proposed six programs including; forest conservation and utilization; fisheries development and management; community tourism development, research and education, and human resources and operations. These programs prescribe measures for restoration, protection, and sustainable management of mangroves in the country (GoK, 2017a)

2.6 Mangrove restoration as a tool for management

Mangrove restoration is considered a management strategy to compensate for the degraded and lost mangrove sites worldwide (Kaly and Jones, 1998; Ellison, 2000; Kodikara *et al.*, 2017). It has the potential to increase mangrove resource base, conservation of biodiversity, coastal protection, and stability, and creates employment for local populations (UNEP, 2014). Mangrove restoration is considered when an ecosystem has been modified to an extent that it can no longer self-correct or regenerate (Lewis, 2005). Given time, however, self-regeneration can occur if the local hydrological regime has not been altered as well as the availability of mangrove seeds or propagules (Saenger, 2003; Lewis, 2005).

Planting and management of mangroves have a long history in Southeast Asia. For example, mangroves of the Sundarbans region of Bangladesh and India have been managed since 1769 (FAO, 1994). Another example is the management of 40, 000 ha of Matang mangroves in

Malaysia for wood products (Watson, 1928). Earlier practices had focused on the rehabilitation of deforested mangroves mainly for silvicultural purposes (FAO, 1994; Ellison, 2000; Saenger, 2003). In a review, Ellison (2000) notes no difference in mangrove management objectives before and after 1982.

Mangrove restoration projects are already proceeding at a large scale in other countries such as India, Vietnam, Malaysia, and Bangladesh, mainly to provide coastal protection in areas prone to the typhoon as well as to generate direct economic benefits to the people (UNEP, 2014; Hai *et al.*, 2020). In addition, mangroves have been replanted in the Philippines for biodiversity conservation and fisheries enhancement (Walters, 2000), coastal defense and protection in Sri Lanka (Kodikara *et al.*, 2017), and to mitigate climate change (Locateli *et al.*, 2014; Wylie *et al.*, 2016; Sidik *et al.*, 2019).

In East Africa, historical information regarding mangrove restoration through planting has not been fully documented (Kairo *et al.*, 2001). Reference is made to mangrove rehabilitation attempts on abandoned saltpans in Tanga, Tanzania which failed because of environmental factors (Semesi and Howell, 1992). In Kenya, past records show that mangroves were planted after clear-felling in Lamu during the First World War (Roberts and Ruara, 1967). However, past reports documented mangrove reforestation in Gazi in the early 1990s aimed at restoring ecosystem integrity and functionality (Kairo *et al.*, 2001). Hitherto, there is no doubt that mangrove restoration programs have been initiated along the Kenyan coast (Kirui, 2013; GoK, 2017a).

Conservation and restoration of mangrove forests are likely to increase given the global realization of their potential role in the achievement of sustainable development goals (SDGs) and the Paris Agreement (Wylie *et al.,* 2016; Howard *et al.,* 2017; Waltham *et al.,* 2020). Specifically, mangroves are strong candidates for climate change mitigation and support a variety of life forms underwater (Nagelkerken *et al.,* 2008; Taillardat *et al.,* 2018). Concerted efforts by governmental, non-governmental organizations, the scientific community, civil societies, and local communities are gaining momentum (UNEP, 2014; Slobodian *et al.,* 2018). For instance, global initiatives such as Global Mangrove Alliance (GMA) and Save Our Mangroves Now (SOMN), have an ambitious mission to prevent and halt mangrove degradation and at the same time increase the present extent by 20% by 2030 (Flint *et al.,* 2018). Their field of action includes mainstreaming mangrove conservation and restoration in global and local political agendas as well as pooling the leading experts and enhance knowledge sharing with an aim of closing the existing gaps (Slobodian *et al.*, 2018).

The UN Decade firms up these efforts by creating an ethical imperative and global movement for ecosystem conservation and restoration (UNGA, 2019; Waltham *et al.,* 2020). This becomes more powerful and effective when tied with the UN Decade of Ocean Science for Sustainable Development which aims to use scientific knowledge and information to protect and restore marine life and its resources (UNGA, 2017). Additionally, the recent report by the High-Level Panel (HLP) for Sustainable Ocean Economy indicates that for every $1 invested in mangrove conservation and restoration generates a benefit of $3, confirming its importance in sustainable development.

2.6.1 Approaches to mangrove restoration

There are two main approaches that have been used. These are natural and artificial regeneration:

2.6.1.1 Natural regeneration

This approach uses naturally occurring mangrove seeds or propagules to restock a degraded forest. Regeneration is from direct, freely falling, and dispersed mangrove propagules, where the composition of species of the regenerated forest depends on the combinations of the adjacent forest and the type of species from where propagules are dispersed. In the Rhizophoraceae family, for example, propagules with pointed hypocotyls freely fall from the parent and can plant themselves into the mud (Saenger, 2003) or be planted away from their parent trees (Lewis, 2005; Kamali and Hashim, 2011). This approach is cheap and results in the establishment of complex and more diverse systems. The major problem of the natural regeneration method is that its establishment may be hindered by hydrological alteration, propagule limitation, and predation of seeds or seedlings by crabs (Lewis, 2000, 2005). Other factors include physical-chemical alterations of soil salinity, pH, as well as abiotic factors (Friess *et al.*, 2020).

2.6.1.2 Artificial regeneration

Artificial regeneration entails direct planting of desired propagules and saplings (<1.2 m high), and rarely the use of small trees (of up to 6 m high) of chosen species at the designated restoration site (Kairo *et al.,* 2001). The use of propagules and nursery raised saplings is the most common method which has been used widely around the world (Primavera and Esteban, 2008). It is, however, in most cases undertaken without first determining possibilities of natural recovery and reasons that hinder natural regeneration (Lewis, 2005). This has subjected most planting efforts to failure due to planting without site assessment, also known as the “garden planting” approach (Lewis, 2009; Lewis *et al.,* 2019). Advantages of using this approach include; ability to control species composition, introduction of genetically improved stocks, and control of pest infestation (Field, 1998; Kairo *et al.*, 2001).

Although artificial regeneration provides a management tool for degraded mangrove ecosystems (Thivakaran, 2017), many problems befall this option. For example, it is expensive where the hydrology regime has been altered (Lewis, 2001). In addition, there is a long-term loss of ecological functionality as evidenced by the simplification of the mangrove ecosystems (Asaeda *et al.*, 2016). Past studies have shown that planting activities have been dominated by the use of single or few mangrove species. For example, species from the family of Rhizophoraceae (*R. mucronata* and *R. apiculata*) have been commonly used in Philippines, Thailand, and Senegal among others (Samson and Rollon, 2008; Cormier-Salem and Panfili, 2016). This has been attributed to their elongated propagules which are easy to collect, handle and plant with ease (Primavera and Esteban, 2008; Lee *et al.*, 2019).

Despite the massive challenges facing mangrove planting, recent documentation has shown remarkable progress and significant output in 24 countries across the world. For the last 40 years, an estimate of 200,000 ha of mangroves has been replanted (Worthington and Spalding, 2018; Table 3). This shows solid evidence on how mangrove restoration is a viable tool to maximize benefits for people and nature (UNEP, 2014).

Table 3. Data summary for global restoration efforts involving mangrove planting

Region	**Number of restoration sites**	**Recorded area (ha)**	**Success**	**Failure**
Australia	1	11	1	0
East and Southern Africa	16	113	11	3
Middle East	3	n/a	3	0
Pacific	0	n/a	n/a	n/a
South America	12	26	10	0
East Asia	1	5	1	0
North and Central America and the Caribbean	8	563	6	0
West and Central Africa	5	14,000	3	1
Southeast Asia	72	47,597	34	16
South Asia	48	127, 832	24	22
Totals	166	190, 147	92	42

Source: Worthington and Spalding, 2018

2.6.2 Success indicators in mangrove restoration programs

Indicators are imperative tools for managers and practitioners to track the performance and ecological functionality of rehabilitated and restored ecosystems (Le *et al.*, 2012). While the effectiveness of a mangrove restoration program is determined by the success indicators there is a paucity of information and data on monitoring (Zhao *et al.*, 2016). This has been limited by a lack of uniform techniques and methodologies used for the evaluation of success. In light of this, assessment of restoration or rehabilitation projects is important to justify the reason whether the project outcomes (objectives and goals) are achieved or not (Field, 1998; Ellison, 2000; Saenger, 2003). There exist different criteria used to evaluate the effectiveness of restoration programs (Le *et al.*, 2012; Wortley *et al.*, 2013). However, extensive discussions that attempt to define a uniform criterion used to evaluate and measure the success of restoration programs still presents several debates (Wortley *et al.*, 2013). The Society of Ecological Restoration International (SERI) developed a primer of nine key attributes that provides guidance and indicators used to evaluate the success of a restored ecosystem in reference to the natural community (SER, 2004).

These attributes have been placed into three categories, namely vegetation structure, ecological processes, and species diversity (Ruiz-Jaen and Aide 2005a).

Vegetation structure is usually determined through the measure of proxies such as tree height, stem diameter, stand density, biomass, canopy cover, and natural regeneration from which plant succession is predicted, while diversity include the number of floral and faunal species present and abundant within different trophic levels (Wortley *et al.,* 2013). On the other hand, ecological processes include measures of reproduction or dispersal, soil development, nutrient cycling, and biological interactions (Table 4; SER, 2004; Ruiz-Jaen and Aide, 2005a). A review on how to measure restoration success by Ruiz-Jaen and Aide (2005b) reveals that the ecological measures have not been well addressed compared to vegetation structure and diversity. This is because they take a longer time to develop and require more resources to measure. In addition, survival rates and the area extent of restored sites are important during the initial establishment phase of a restoration program (Le *et al.,* 2012).

Reviews by Field (1998) and Ellison (2000) gives great insight into the importance of designing a success criterion before embarking on a mangrove restoration project. Having clear restoration goals in mind is imperative to match the implementation of a restoration project; thus, provides a basis for evaluation of success. This has been emphasized by Le *et al.,* (2012) where authors argue that restoration success is more than just trees but goes beyond ecological and social-economic sustainability. However, if the objective of the restoration is to enhance ecosystem resilience and functionality, success indicators need to go beyond vegetation proxies and include socio-economic impacts as shown in Table 4 (Higgs, 1997; Le *et al.,* 2012; SER, 2004).

Survival rates and area extent are success indicators that have dominated studies during the establishment phase of replanted mangroves. This includes studies in the Philippines, Sri Lanka, and Thailand (Kodikara *et al.,* 2017; Wodehouse and Rayment, 2019). Few studies have reported success indicators on the development phase which depicts the long-term recovery and functionality as well as socio-economic impacts of a restored mangrove ecosystem (Kairo *et al.,* 2009; Uddin *et al.,* 2014; Sillanpaa *et al.*, 2017). The recovery of the ecological functionality of a mangrove ecosystem also underscores both floral and faunal (crabs, mollusks, fish species) recruitment.

Table 4. The success criteria used to monitor the success of a restoration program

No	**Classification criteria**	**Functional indicators**
1	Establishment indicators	Survival rate, area planted and canopy cover,
2	Vegetation structure	Tree growth performance: height, diameter, basal area, stem form, stand density, canopy cover, litter cover, and natural regeneration,
3	Species diversity	Flora and fauna: number of species, abundance, and special life forms,
4	Ecological processes	Biogeochemical cycles and nutrient cycling: litterfall, decomposition, soil organic matter, carbon fixation, and mineralization,
5	Socio-economic	Employment opportunities, local income, livelihood opportunities, food availability and fibre supply, stability of market prices, and local empowerment and capacity.

Source: SER, 2004; Le *et al.*, 2012

2.6.3 Factors affecting the success of mangrove restoration programs

Many attempts to restore degraded and lost mangroves have presented mixed results of both success and failure around the world (Field, 1998; Lewis 2005; Samson and Rollon, 2008; Kodikara *et al.,* 2017). Therefore, it is challenging to generalize the sites to successfully restore mangroves given the fact that mangrove forests are controlled by various interacting factors:

tides, periods of freshwater influx, wave action, the topographical position, soil, and water salinity, and the patterns of sedimentation (Ellison, 2009; Friess, 2016; Primavera *et al.*, 2019).

When contemplating to rehabilitate damaged or lost mangroves, special attention must be taken to consider the following factors; site selection and species match (Lewis, 2005, 2009; Hai *et al.,* 2020), hydrological regimes, and salinity thresholds of mangroves species (Turner and Lewis, 1996), tidal and wave energy (Kamali and Hashim, 2011), propagule availability (Lewis, 2005), planting techniques (Primavera *et al.,* 2012) involvement of local stakeholders Dharmawan, *et al.,* 2016) thinning and spacing (Kairo *et al.,* 2001) the cost of mangrove restoration (Lewis, 2001), and objectives and goals of restoration (Ellison, 2000; Saenger, 2003; Stokes *et al*., 2016).

Planting of mangroves is recommended when there is propagule limitation, for production forestry, for enrichment planting to introduce new species and for research and education purposes (Saenger, 2003; Lewis, 2005). While artificial regeneration can be used to return the lost or degraded mangrove forests (Thivakaran, 2017), non-mangrove areas including; seagrass beds, mudflats, and sandflats should be avoided (Lee *et al.,* 2019). For instance, in the Philippines, 44,000 ha of a mangrove project failed due to planting on mudflats and sandflats (Lewis, 2001) while in Senegal, about 150 million *Rhizophora* propagules supposedly translating to 12,000 ha cannot be detected as a result of mass failure (Alexandris *et al.,* 2013). This shows how site selection and species mismatch have a significant impact on the project output. Other factors reported include biophysical disturbances such as cattle browsing and trampling which led to low survival rates across all the project areas in Sri- Lanka (Kodikara *et al.,* 2017).

Furthermore, there exist several multi-human factors inherent to mangrove restoration practices. This includes institutional arrangement and research – the political ecology of mangrove management (Thompson, 2018). The success of restoration programs is underpinned by the effectiveness of stakeholders' integration through participatory approaches (Waltham *et al.,* 2020). For example, the failure of the mangrove restoration projects in Indonesia was linked to ignorance of local politics and weak research that failed to involve the lower-class citizens (Dharmawan *et al.,* 2016). Moreover, mangrove restoration failures were duplicated in Thailand due to unequal and weak actor relations resulting from a lack of (Thompson, 2018). Additionally, power asymmetries, inadequate institutional capacities, and different cultural ideologies created gaps amid policy formulation and implementation, thus leading to poor environmental management and governance (Thomson, 2018). Therefore, it's imperative to note that mangrove restoration is not a stand-alone process but rather needs concerted efforts involving all key stakeholders at a landscape level to ensure its success and sustainability (Datta *et al.,* 2012; Thomson, 2018).

While the adjacent communities are the gatekeepers of the project activities, their active involvement is central to the success of mangrove restoration (Abdullah *et al.,* 2011; Datta *et al.*, 2012; Romanach *et al.,* 2018). Most importantly, community willingness to participate in mangrove conservation and restoration should not be overlooked. This is because their participation is determined by tangible benefits accrued from such practices (Melana *et al.,* 2000). For instance, in the Volta catchment area in Ghana, the primary factors that motivated the local communities to participate in restoration and management included their livelihoods and economic benefits accrued (Aheto *et al.,* 2016) while in Perak and Selangor in Malaysia, financial compensation of community participants dominated (Abdulla *et al.,* 2014). Past studies have shown that ecological interests alone are not enough to enhance sustainable restoration and management of mangroves but can be boosted through financial compensation and economic incentives (Aheto *et al.,* 2016; Wylie *et al.,* 2016).

Nevertheless, successful approaches that involve the application of ecological principles of restoration have been developed and modified by mangrove restoration practitioners, scientists, and students (Lewis and Marshall, 1997; Stevenson *et al.,* 1999; Brown and Lewis, 2006; Bosire *et al.,* 2008; Lewis *et al.,* 2019). These approaches are holistic and integrated which recommends mangrove planting as the last option to mangrove restoration.

2.7 Theoretical Framework

This research study is underpinned by the theory of change (Weiss, 1995). The theory describes how and why an initiative works by providing a link between the activities and the outcomes. As such, the theory provides the need for monitoring and evaluation of initiatives to determine the progress and the possible achievement of the proposed set targets as well as the contextual factors that may affect the success of plan implementation. Therefore, this theory supports this study in the perspective of assessment and monitoring of mangrove restoration projects as well as their outcomes. For this reason, monitoring and evaluation of mangrove projects are vitally important to determine their success and/ or failure. Consequently, it enables documentation of challenges and proposes suitable measures and possible adjustments that are important in mainstreaming and adjustment of the implementation plans to ensure cost-effective and successful mangrove restoration.

2.8 Conceptual Framework

From the literature, it is quite clear that planning for the assessment, monitoring, and evaluation of restoration projects is a complex entity (Le *et al.*, 2012). This is because it involves various objectives and a multitude of success indicators ranging from ecological to socio-economic gauges (Table 4). Due to a lack of uniformity in techniques and methodological approaches to evaluating success, it is difficult to develop an integrated restoration plan and model that integrates all the indicators of success (Ruiz Jaen and Aide 2005). However, based on the study approach, a conceptual framework is presented that captures the relevant success indicators (colored; Fig 2) that were used to assess the recovery of the restored mangrove ecosystem. This framework consists of early phase (establishment) success indicators (survival rates and area extent), and the building phase indicators – forest growth parameters (tree height, diameter, and biomass) and species composition (flora and macrofauna). The cited indicators assessed are not independent because they are influenced by age, site conditions, and silvicultural management practices of the restoration program. The interplay affects the short and long-term outcomes of the individual indicators. In addition, the framework captures drivers for success or failure along with the community perception of restoration practices. In the end, this model provides room for feedback and adjustment to allow amenable updates and changes as new knowledge accrues.

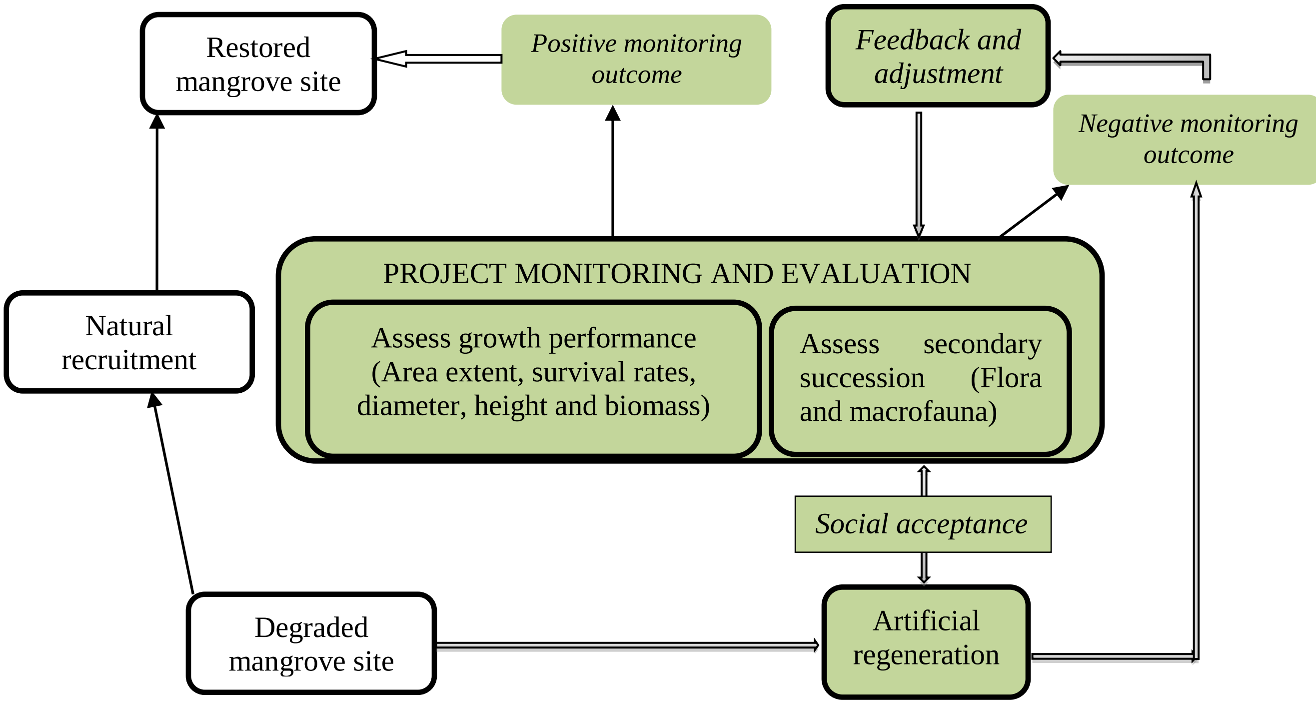

Figure 2: Conceptual framework for mangrove restoration, monitoring and evaluation (Modified from Bosire *et al.*, 2008).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Description of the study area

The study was conducted along the Kenyan coast from the Kenya - Somalia border in the north; to Kenya - Tanzania border in the south between longitudes 41°34′E and 39°17′E and latitudes 1°40′S and 4°25′S (Fig. 3). The distinct feature of the Kenya coast is the fringing reef system that runs parallel to the coastline. The coastal zone is characterized by plateaus and plains with kaolinitic and montmorillonitic soils dominating mangrove areas (GoK, 2017a). Rivers draining through the coastal zone have high seasonal variability with Sabaki and Tana rivers being the only permanent rivers draining into the Indian Ocean. Seasonal rivers include river Mkurumudzi, Umba and Ramisi in the south coast. The coastal region experiences a hot and humid tropical climate with temperatures ranging between 24°C and 30°C. With the bimodal seasons of rainfall, the long rain season (March to May) occurs during the Southeast Monsoon while the short rains (October to November) occur during the Northeast Monsoon (Bosire *et al.*, 2003).

Mangroves cover an estimated area of 61, 271 ha in Kenya (GoK, 2017a). They are located in the protected bays, tidal estuaries, and creeks of the five counties, namely Kwale, Mombasa, Kilifi, Tana River, and Lamu (Fig. 3). The largest formation which consists of 70% of mangroves is found in areas north of Tana River in Lamu (Kirui *et al.*, 2013). Lamu and Tana delta form the most productive mangroves due to the influence of upwelling conditions to the north and freshwater and nutrient supply from the hinterland by River Tana, respectively (Bosire *et al.*, 2016). Small formations of mangroves are found at the mouths of seasonal rivers at the south coast; in Gazi bays, Shimoni-Vanga system, and the creeks of Tudor and Port Reitz of Mombasa.

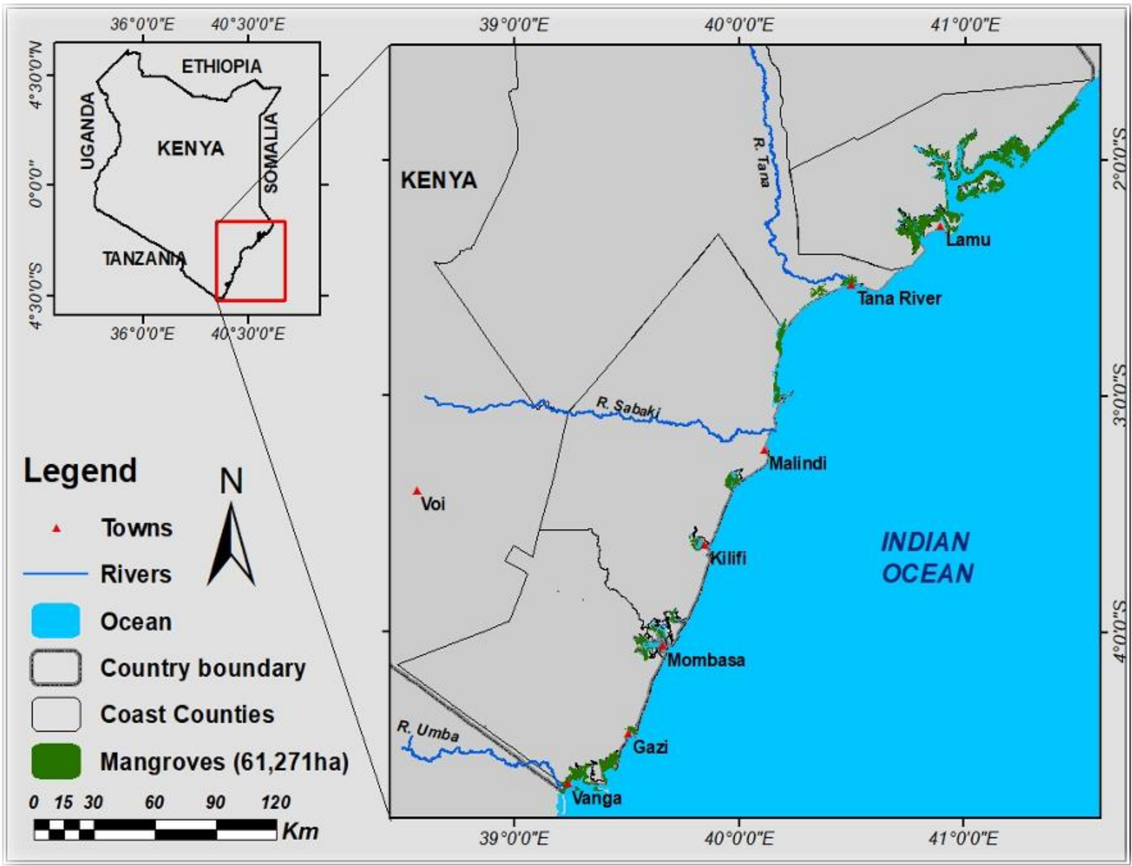

Figure 3. Map of Kenya showing the location of mangrove forest along the Kenyan Coast; Source: Author, 2021

All the nine mangrove species in Eastern Africa are found in Kenya. They display a zonation pattern from seaward to landward (FAO, 2003); a typical pattern is *Sonneratia alba* S.m, *Rhizophora mucronata* Lam, *Bruguiera gymnorrhiza*, *Ceriops tagal* C.B Robinson, *Avicennia marina* Forssk, *Xylocarpus granatum* J. Koenig, *Xylocarpus mollucensis* Lam, *Lumnitzera racemosa* Var, and *Heritiera littoralis*. This pattern is influenced by salinity, soil substrate, and tidal regimes (Friess, 2016).

Mangrove forests provide valuable goods and services to adjacent coastal communities (Kairo *et al.,* 2009; GoK, 2017a; Owuor *et al.,* 2019). Despite their importance, Kenya has lost approximately 50% of mangroves over a period of 50 years (FAO, 2005) while approximately 18% has been lost between the years 1985 and 2009 (Kirui *et al.,* 2013). Past study has shown that at least 40% of the present stands are perceived to be in degraded conditions (GoK, 2017a). Degradation and loss of mangroves have been attributed to overexploitation for wood products (firewood and building poles), land-use conversion (salt-pans and infrastructure) impacts from land use-based activities (siltation), pest infestation as well as climate change-related impacts (Abuodha and Kairo, 2001; Bosire *et al.,* 2014; Jeno *et al.,* 2019; Mungai *et al.,* 2019).

In the realization of continued degradation and loss of mangrove ecosystem benefits, trial mangrove reforestation was initiated in Gazi Bay in the early 1990s (Kairo *et al.,* 2001). Over the years, conservation and restoration practices have increasingly gained momentum with government and non-governmental agencies supporting the community initiatives along the Kenyan coast (GoK, 2017a).

3.1.1 Social-economic status

According to the 2019 census, the total population in the coastal region was reported to be 3.98 million persons (KNBS, 2019). This population depends on mangrove resources either directly or indirectly. The main sources of livelihoods are fishing, tourism, and mangrove harvesting while in the hinterland, livestock rearing and subsistence farming are the major occupations (GoK, 2017b). Such activities contribute differently to coastal economy: tourism (45%); ports and shipping (15%); agricultural production (8%); fishing (6%); agriculture (5%); forestry (4%); and mining (2%) (KNBS, 2016). While mangroves and their related activities contribute to the coastal economy, the surrounding communities highly depend on mangroves for wood products as well as fisheries for their direct sources of livelihood.

3.2 Research design and methodology

The study adopted vegetation and social survey approaches. Vegetation surveys were done in the counties of Kwale, Mombasa, Tana River, and Lamu, mainly targeting areas where restoration initiatives have been established. This involved random establishment of 10m × 10m square quadrats along a transect perpendicular to the waterline on a replanted mangrove site. Assessment of survival rates was limited to plantations between 3 and 60 months while vegetation structural attributes were assessed in selected plantations with ≥5 years of age. Handheld Global Positioning System (GPS) tool was used to mark the location of replanted sites. To complement the study, available secondary data on mangrove program objectives were reviewed while a structured and semi-structured questionnaire was used to evaluate community perceptions of restoration practices. Community interviews were done in three project areas of Kwale and Mombasa (Vanga, Gazi, and Mikindani) due to their long-time existence and intense restoration over the years. Purposive sampling was employed to administer the questionnaire where a total of 106 respondents including 7 key informants were interviewed.

3.2.1 Vegetation survey

The vegetation survey involved the assessment of success indicators on replanted mangroves. These included growth parameters such as survival, height, diameter, stocking density, and secondary succession.

3.2.1.1 Forest structure and productivity

Assessment of survival rates was done in young plantations. Within 10m × 10m^2 quadrats, all surviving trees were counted and recorded. In addition, the date of planting, spacing, and total planted mangroves within a site were recorded (Kodikara *et al.*, 2017).

The forest structural attributes were investigated in replanted mangroves with ≥5 years of age using the recommended protocol (Kauffman and Donato, 2012). Within 10 ×10m^2 established quadrat, all trees with a diameter ≥2.5 cm were identified and counted. Vegetation parameters measured included tree height and stem diameter at 1.37m above the ground. For *Rhizophora* trees, stem diameters were measured at 30cm above the highest prop root. Forest caliper and graduated pole were used to measure tree diameters and heights respectively. From the data collected, annual growth increment (diameter and canopy height), stand density (stems/ha), and above-ground biomass (t/ha) were derived. Mean Annual Increments (MAI) in growth parameters were derived by dividing mean growths by the age of plantations. Wood specific gravity/density for each mangrove species was used in accordance to values from Gillerot *et al.*, (2018) to calculate aboveground biomass using allometric relations (AGB= $0.251\rho D2.46$); where AGB = Above Ground Biomass (t/ha), ρ = wood gravity g/cm^3, D = diameter at breast height (Komiyama *et al.*, 2005).

3.2.1.2 Natural recruitment

Data on natural regeneration was obtained through Linear Regeneration Sampling (LRS) whose application can be found in Sukardjo (1987), FAO (1994), and Kairo *et al.*, (2002). Subplots of 5m× 5m^2 were established within 10m× 10m^2 quadrat for assessment of natural regeneration. The recruitment of juveniles was recorded in accordance with their heights and assigned as regeneration classes (RC) I, II, or III (FAO, 1994). Saplings below 40cm were classified as RCI, saplings between 40cm and 150cm assigned to class RCII, while small trees greater than 150cm but less than 300cm in height were classified into RCIII.

3.2.1.3 Macrofaunal composition

Assessment of macrofauna composition (mostly crabs and mollusks) was restricted to Gazi and Mikindani plantations. Two $1m \times 1m^2$ sub-plots were randomly placed within $10m\times 10m^2$ quadrat for the identification and quantification of macrofauna. The observer remained motionless for at least 15 minutes before commencing the observation. This was done at 3.5 m away from the quadrat (Skov and Hartnoll, 2001). Observation involved species identification and counting of crabs using a binocular (Skov and Hartnoll, 2001; Skov *et al.,* 2002) while mollusks were identified and counted at the side of the sub-plot. Species identification was done using dichotomic identification keys by Richmond (2011). Shannon Weiner Biodiversity index (H) and the index of evenness (E) were used to determine the macrofauna species richness and abundance (Nollan and Callahan, 2006). The Shannon - Wiener index is given by;

$$H = -\sum_{i=1}^{s} (\text{Pi} \times \text{In Pi})$$

Where **H** is the species diversity index, **s** is the number of species and $\mathbf{P_i}$ is the species individual proportion that belongs to the i^{th} species of the total number of individual species.

$$E = H/\text{In } S$$

Where **E** is the species evenness, **H** is the Shannon Wiener Index and **S** is the species richness.

3.2.2 Social Surveys

Purposive sampling was used to administer a questionnaire for individual survey interviews. This is because the study had targeted individuals who have participated or active in mangrove reforestation activities. Population sample (n) was calculated using Cochran's (1977) formula given below.

$$n_0 = \frac{Z^2pq}{e^2}$$

Where **Z** is the selected alpha level, ***p*** is the estimated proportion of the population, ***q*** is 1-*p* and ***e*** is the level of precision. With a 95% confidence interval, the study sample size was calculated at 136 respondents from the sampling frame of 200 participants in the three villages. These were distributed proportionately according to the population of the sampled villages. However, due to time constraints and unavailability of all targeted respondents during the study period, a total of 107 respondents were interviewed including the key 7 informants.

To triangulate the results from individual surveys, an in-depth interview with 7 key informants was conducted. This involved the key actors in CFAs and CBOs as well as resourceful persons identified through the snowball technique (Atkinson and Flint, 2001). Specific data collected included funding agencies, names of conservation groups, perceived challenges, and motivation to participate in reforestation activities among others. To complement this, a desktop review of secondary data was done to capture the objectives of restoration programs.

3.3. Statistical analysis

Data analysis employed different forms of software. To develop a geolocation map, GPS points were uploaded into Arc GIS software containing the site shapefiles and also to estimate the area in addition to planting matrix estimation. MINITAB 14.0 software package was used to analyze the growth parameters of replanted mangroves while survival rates were determined through aggregation based on the dead/alive in terms of percentages. Inferential statistics, particularly One-way Analysis of Variance (ANOVA) was used to test for significant variations in mean growth parameters. In all the statistical tests done by ANOVA, the test of significance was set at $\alpha \leq 0.05$ (95% confidence interval). Qualitative data was reviewed, explored, and coded into themes using presented in narratives. On the other hand, quantitative data from the social survey were organized using SPSS software version 20 and analyzed through descriptive statistics, and presented using graphs.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Results

4.1.1 Geolocation, areal extent and the choice of mangrove species replanted

The study identified total of 19 project sites across the four counties where mangrove reforestation activities have been established along the Kenyan coast (Fig. 4; Table 5). These sites constituted a total of 53 replanting efforts surveyed. Mangroves were planted on different locations in regards to inundation classes characterized as intertidal (low, mid, and high) zones where mangroves were perceived to be degraded. Out of 53 planting efforts, 33 were located in the mid intertidal zone while 13 and 7 efforts were located in high and low zones, respectively.

Mombasa county dominated in the number of planting efforts and area extent followed by Kwale, Lamu, and Tana River. The area extent at project areas ranged from 0.5 – 20 ha (mean: 4.92±5.75) translating to a total estimate of 93.5 ha. This depicts that mangrove restoration in Kenya is in small scale which mainly targeted reforesting (enrichment planting) degraded sites within the existing mangrove forests. *R. mucronata* (52%) was the most preferred mangrove species for planting followed by *C. tagal* (28%), *A. marina* (9%), *B. gymnorrhiza* (7%), and *S. alba* (4%). Out of 9 mangroves species found in Kenya, five mangrove species were observed at replanted sites mainly as monospecific or pure stands. Gazi system had the highest number (6) of mangrove species replanted compared to other sites that used between 1-3 species (Table 5).

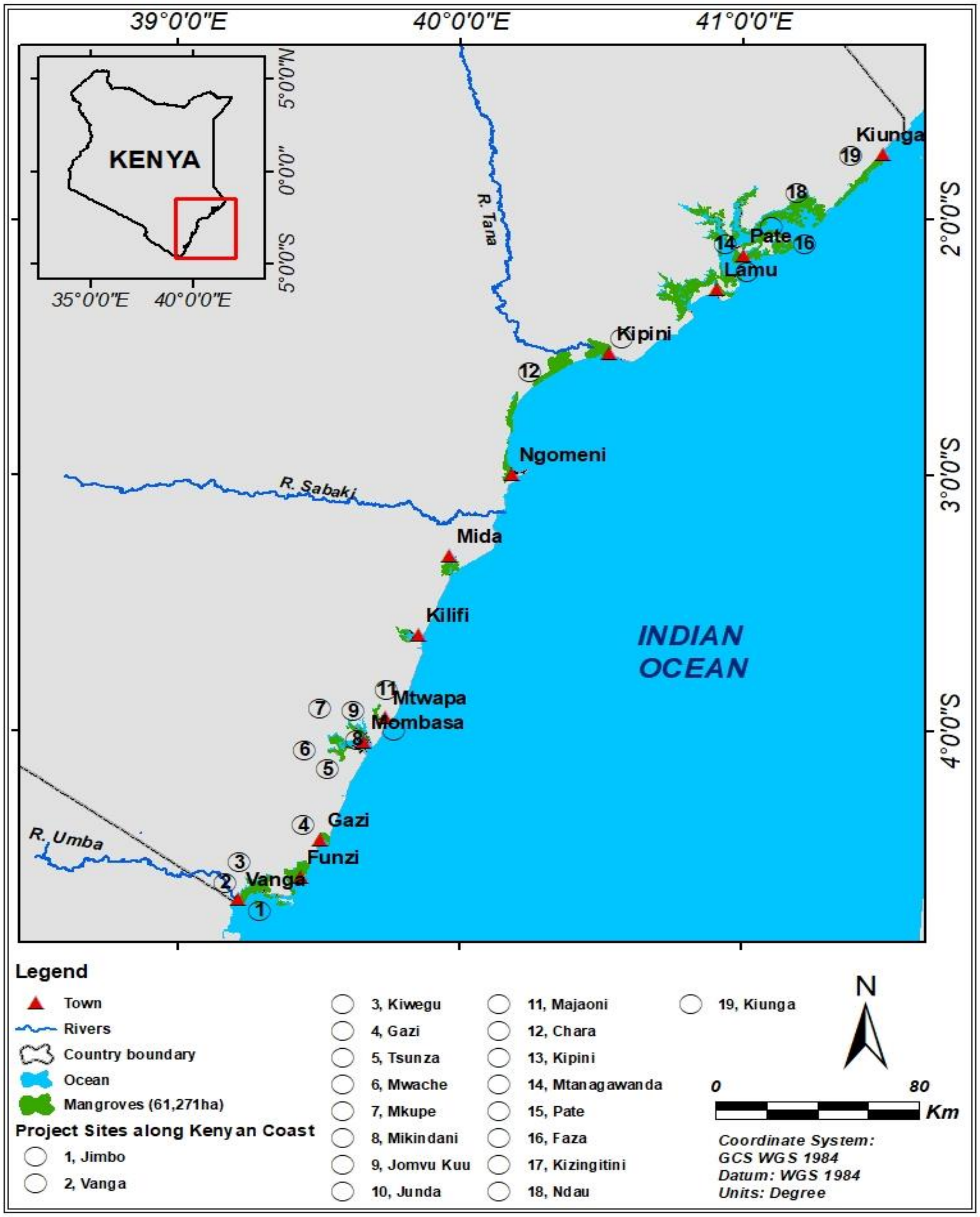

Figure 4: Location of mangrove project sites along the Kenyan Coast; Source: Author, 2021

Table 5: Mangrove reforestation in Kenya

County	Project area	Southings	Eastings	No of planting efforts	Total area (ha)	Survival rates (Mean +SD)	Species planted
Kwale	Jimbo	04^0 40' 736"	039^0 12' 491"	5	8	57.9±38.5	*R. mucronata, A. marina, C. tagal, B. gymnorhiza*
	Vanga	04^0 39' 102"	039^0 13' 164"	3	5	48.7±10.8	*R. mucronata, A. marina, C. tagal,*
	Kiwegu	04^0 38' 183"	039^0 13' 620"	4	2	24.8±31.2	*R. mucronata,*
	Gazi	04^0 25' 45.9"	039^0 30 39.8"	4	20	37.7±30.9	*R. mucronata, A. marina, C. tagal, B. gymnorhiza, S. alba*
	Tsunza	04^0 04' 16.0"	039^0 33 30.1"	2	2	23.8±33.6	*C. tagal*
Mombasa	Mwache	04^0 01' 45.7"	039^0 32 36.9"	2	2	33.8±19.5	*R. mucronata, C. tagal, A. marina*
	Mikindani	03^0 59' 38.0"	039^0 38 18.1"	8	17.3	76.7±15.9	*R. mucronata, C. tagal, B. gymnorhiza*
	Jomvu Kuu	03^0 59' 39.4"	039^0 38 12.2"	2	2.5	84.2±11.5	*R. mucronata*
	Majaoni	03^0 95' 649"	039^0 70' 922"	3	13.5	60.7±47.1	*R. mucronata, C. tagal, A. marina*
	Mkupe	04^0 02' 280"	039^0 56' 952"	4	4	66.7±33.5	*R. mucronata, C. tagal*
	Junda	04^0 01' 01.2"	039^0 66' 930"	3	5	60.1±1.9	*R. mucronata*
Tana River	Kipini	02^0 31' 41.3"	040^0 30' 52.6"	1	1	12.4	*R. mucronata, C. tagal, B. gymnorhiza*
	Chara	02^0 34' 04.4"	040^0 20' 44.8"	2	1	93.8±5.5	*C. tagal, A. marina, B. gymnorhiza*
Lamu	Faza	02^0 03' 00.0"	041^0 12' 12.8"	1	2	32	*C. tagal A. marina,*
	Pate	02^0 15' 34.5"	041^0 00 21.3"	2	3.5	89.4±5.2	*R. mucronata, C. tagal*
	Kizingitini	02^0 03' 46.5"	041^0 08' 18.3"	2	1.2	90.1±1.5	*R. mucronata, C. tagal*
	Mtangawanda	02^0 07' 15.7"	040^0 58' 21.4"	2	1	60.1±26.4	*R. mucronata, B. gymnorhiza*
	Ndau	02^0 00' 09.4"	041^0 12' 12.8"	1	0.5	47	*R. mucronata*
	Kiunga	02^0 31' 39.5"	040^0 30' 54.4"	2	2	48.7±61.9	*R. mucronata*
Total	19			53	93.5	55.4±31.2	**

4.1.2 Growth performance of replanted mangroves

4.1.2.1 Survival rates

The mean survival rates at the project sites are given in Table 5. The survival rates for individual sites ranged from 0 – 97.8% (mean: 55.4±31.2%). Out of 53 planting efforts, 5 replanting attempts in Jimbo and Kiwegu showed no surviving plants. In addition, 7, 9, and 32 attempts ranged from 5 – 20%, 30 – 50% and >50%, respectively. Out of 19 project sites, 11 recorded mean survival rates higher than 50%. All the project sites in Mombasa showed a higher mean survival rate ≥60% except Mwache which recorded 33.8%. This is contrary to Kwale county where all the project areas had mean survival <50% except Jimbo. Tana River and Lamu counties showed high ranges of low and high survival rates.

In comparison, Mombasa county recorded higher mean survival of 71.7% followed by Lamu, Tana River, and Kwale at 67.6%, 66.7%, and 40.7%, respectively. Concerning zonal elevation, the mid intertidal zone recorded higher survival rates (72.6%) than near shore and landward sites that recorded survival of 41.2% and 35.7% respectively.

4.1.2.2 Forest structural attributes of replanted mangroves

Mean Annual Increments (MAI) in height and diameter varied among species and age of the plantation as shown in Table 6. MAI in terms of height and diameter for *R. mucronata* species ranged from 0.12 – 0.57m/yr and 0.17 – 0.49cm/yr while *C. tagal* ranged from 0.11 – 0.28m/yr and 0.12 – 0.25cm/yr, respectively. In addition, *S alba* species ranged from 0.31 – 0.47m/yr and 0.31 – 0.52cm/yr. In all observed parameters, *C. tagal* showed the lowest growth rate in MAI in terms of height and diameter of 0.11m/yr and 0.12cm/yr respectively. Compared to *C. tagal,* the growth of other species: *R. mucronata* and *S. alba* were substantially faster. In terms of stem elongation, the growth rate was higher in 24-year-old *R. mucronata* (0.57m/yr) while 14-year-old *S. alba* had the highest increment in terms of diameter (0.52cm/yr) (Table 6). Generally, the ANOVA test revealed a significant difference for both diameter ($F_{(5,17)} = 20.89$, $p < 0.05$), and height ($F_{(5,17)} = 16.90$, $p < 0.05$) respectively among species.

Table 6. Structural attributes of replanted mangroves along the Kenyan Coast

Location	Species	Age (year)	Mean height(m) (Mean±SD)	MAI in height (m)	Mean dbh (cm) (Mean±SD	MAI in dbh (cm)
Jimbo	*Rhizophora mucronata*	14	3.83±1.10	0.27	3.31±0.63	0.23
Vanga	*R. mucronata*	14	2.31±0.32	0.12	2.36±0.77	0.17
Gazi	*R. mucronata*	24	13.68±2.23	0.57	11.34±1.19	0.47
Gazi	*R. mucronata*	18	6.57±0.63	0.38	6.49±0.49	0.36
Mikindani	*R. mucronata*	9	2.61±0.15	0.29	2.95±0.18	0.32
Mikindani	*R. mucronata*	7	2.35±0.22	0.34	2.74±0.39	0.33
Jomvu	*R. mucronata*	5	1.91±0.27	0.38	2.48±0.41	0.49
Majaoni	*R. mucronata*	8	3.20±0.55	0.40	3.26±0.64	0.41
Junda	*R. mucronata*	5	2.35±0.37	0.47	2.59±0.36	0.51
Gazi	*Ceriops tagal*	24	6.65±0.61	0.28	5.88±1.07	0.25
Gazi	*C. tagal*	22	2.41±0.75	0.11	2.53±0.45	0.12
Gazi	*Sonneratia alba*	14	6.27±1.69	0.47	7.27±0.57	0.52
Gazi	*S. alba*	10	3.12±0.76	0.31	3.08±0.91	0.31

On the other hand, stand density and biomass ranged from 3575 – 7825 stems/ha and 14.0 – 375.9 t/ha for 5 – 24-year-old plantations as shown in Table 7. MAI in biomass ranged from 2.02 – 15.67t/ha for the same plantations. Results from ANOVA revealed a significant difference in mean stand densities ($F_{(5,17)} = 9.62$, $p = 0.001$) and biomass ($F_{(2,11)} = 20.36$, $p = 0.0004$), at 95% confidence interval. It was observed that these parameters varied among species and the age of the plantations.

Table 7. Stand density and biomass in selected mangrove plantations

Site	Mangrove plantation	Age (year)	Number of plots	Stand density (stems/ha)	Biomass ±SD (t/ha)	MAI in biomass (t/ha)
Kinondo	*R. mucronata*	24	4	3625±793	375.9±110.85	15.67
Gazi	*R. mucronata*	18	4	3575±830	87.6±19.42	4.87
Gazi	*S. alba*	14	2	5425±1272	178.3±11.96	12.74
Jimbo	*R. mucronata*	14	1	3600	16.10	1.14
Mikindani	*R. mucronata*	9	4	7825±1118	25.5±4.64	2.83
Mikindani	*R. mucronata*	7	1	5200	14.0	2.02
Junda	*R. mucronata*	5	2	3850±494	12.29±2.37	2.46

Natural regeneration

The density of recruited juveniles in selected mangrove plantations is given in Table 8. Juvenile densities varied within species and age of the plantation. Lower regeneration classes (RCI) showed high densities across the assessed plantations when compared to the established RCII and RCIII juveniles. The 18 yrs. old *R. mucronata* recorded 7150 juveniles/ha of naturally recruited wildings compared to 14 yr. *S. alba* plantation that had 175 juveniles/ha. It was found that the regeneration ratio, RCI: RCII: RCIII, (e.g 5:3:1) was lower than that of natural forests with rapid regeneration.

Table 8. Juvenile densities in replanted mangroves

Site	Species planted	Age (years)	Stand density/ha	Regeneration classes I	II	III	Total juveniles/ha
Gazi	*R. mucronata*	24	3625	825	375	25	1225
Gazi	*R. mucronata*	18	3575	5250	1625	275	7150
Gazi	*S. alba*	14	5425	100	75	0	175
Jimbo	*R. mucronata*	14	3600	700	600	440	1740
Mikindani	*R. mucronata*	9	7825	650	600	250	1500
Junda	*R. mucronata*	5	3850	300	250	150	700

Macrofaunal (crabs and mollusks) recruitment

Species distribution and abundance in selected mangrove plantations are shown in Table 9. Shannon diversity index and evenness (E) ranged from 1.60 – 1.87 and 0.85 – 0.96, respectively. The diversity of macrofaunal invertebrates (crabs and mollusk) was high in the 14-year-old *S. alba* plantation of Gazi (H=1.87) and low in 24 - year-old *R. mucronata* plantation. The key crab species included *Perisesarma guttatum* and *Neosarmatium smithi* while *littoraria* (mollusc) species was observed across the plantations. However, it was also observed that there was a difference in the type and number of species distribution in replanted mangrove sites.

Table 9. Recruitment of macrobenthic fauna (crabs and mollusks); in the parenthesis is the age of plantation

	Mangrove planted site			
Site	**Gazi**	**Gazi**	**Gazi**	**Mikindani**
Species	*R. mucronata (24)*	*R. mucronata (18)*	*S. alba (14)*	*R. mucronata (9)*
Plot size	$1m^2$	$1m^2$	$1m^2$	$1m^2$
Perisesarma guttatum	14	9	0	7
Neosarmatium smithi	2	2	0	3
Neosarmatium meinerti	3	4	0	0
Celiopagurus strigatus	0	2	2	0
Metagraspus thukuhar	0	0	4	0
Metagraspus oceania	0	0	6	0
Ilyograpsus paludicola	0	0	5	0
Uca chloropthalmus	5	0	0	3
Total crabs	**21**	**17**	**15**	**13**
Littoraria scabra	10	13	6	9
Littoraria pallescens	0	9	4	3
Cerithidea decollata	3	23	0	11
Terebralia palustris	0	0	2	0
Total mollusks	**13**	**45**	**12**	**23**
Total species number	6	5	7	6
Grand total	**34**	**62**	**29**	**36**
Species Evenness (E)	0.86	0.85	0.96	0.92
Shannon Diversity (H)	**1.60**	**1.65**	**1.87**	**1.64**

4.1.3 Community perception towards mangrove restoration practices

A review of the secondary information from management plans and project documents focused on the eight objectives (Table 10). Three objectives including rehabilitation of mangroves, community development, and promotion of IGAs dominated across the programs followed by fisheries (5), education (4), shoreline protection (3), climate mitigation, and waste management (2). From the community perspective, 42.5% of the respondents perceived the purpose and the objective of mangrove programs as environmental conservation, followed by community development (27.9%), climate change mitigation (21.8%), and legislation compliance (7.8%).

Table 10. A review of mangrove restoration objectives by different programs

Program Objectives	Mikoko Pamoja	Bigship	VAJIKI CFA	Brain Youth Group	COMENSUM	LTDCT	PMCC	Total
Rehabilitation of mangroves	✓	✓	✓	✓	✓	✓	✓	8
Community development	✓	✓	✓	✓	✓	✓	✓	8
Climate change mitigation	✓	×	✓	×	×	×	×	2
Shoreline protection	✓	×	✓	×	✓	×	×	3
Mariculture/fisheries	✓	×	✓	✓	✓	×	✓	5
Promote IGAs	✓	✓	✓	✓	✓	✓	✓	8
Waste management	×	✓	×	✓	×	×	×	2
Research and education	✓	✓	✓	×	✓	×	×	4

However, most of the respondents (77.8%) cited mangrove reforestation as a difficult task given the nature of its environment, unlike 22.2% who said it is easy. Besides, the key actors interviewed highlighted inadequate resources (funds), lack of knowledge on mangrove regeneration techniques, illegal harvesting, and grassroots politics as the major setbacks that hindered the short and long-term achievement of the program goals. Despite such challenges, respondents who participated in reforestation practices were motivated by the need for;

environmental conservation and preservation, wages (financial compensation), increased fisheries, wood products, and community development (Fig. 5). Other factors included climate change mitigation and biodiversity conservation.

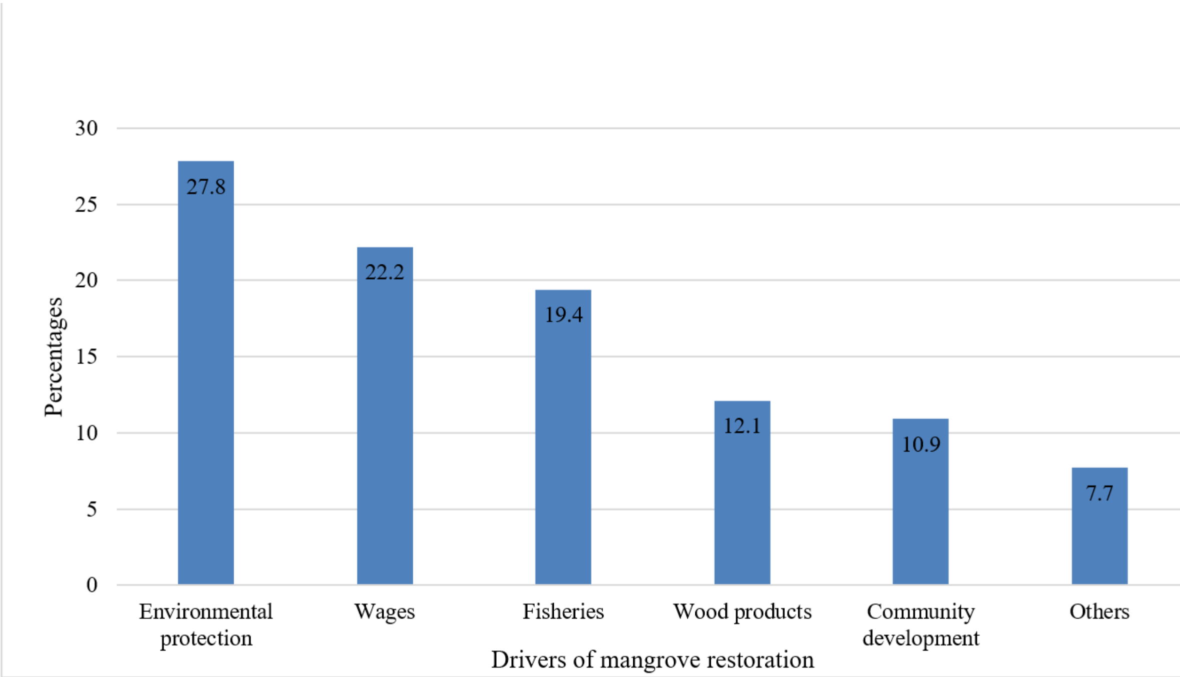

Figure 5: Community motivation for mangrove restoration activities.

The key actors participating in mangrove restoration in Kenya were categorized into local community groups, government, and non-governmental organizations (national and international) (See appendix I). The local community groups include registered community-based organizations (CBOs) and community forest associations (CFAs). The government agencies played a crucial role by providing financial input as well as technical support to the local communities through training on effective conservation and restoration management practices. This was a clear indication of a concerted and integrated approach to mangrove conservation and management (Fig. 6)

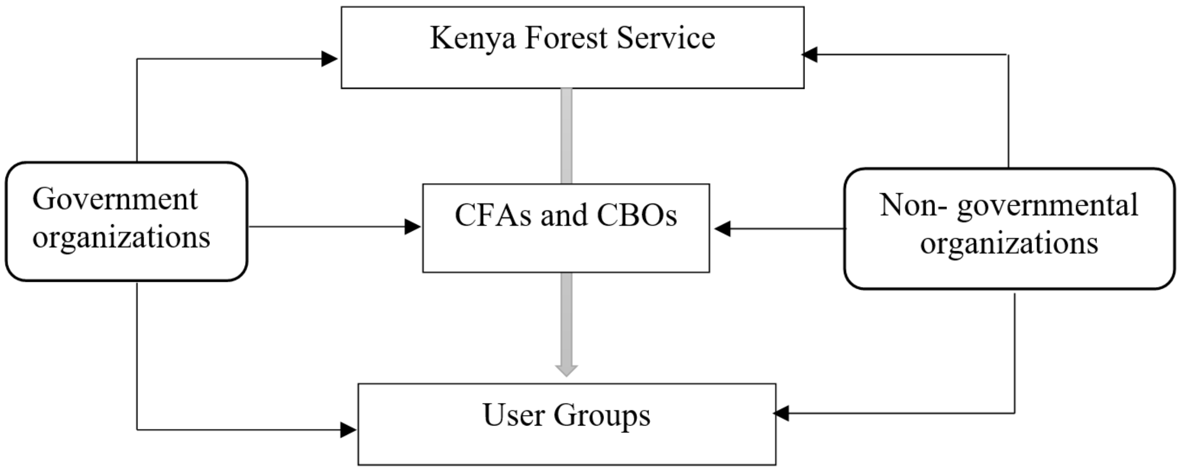

Figure 6: A framework showing stakeholder participation in mangrove restoration in Kenya; *Source:* Author, 2021

On the other hand, the study identified several funding agencies that supported mangrove restoration programs in Kenya. The agencies provided financial inputs to support the buying of mangrove seedlings, the establishment of nurseries, monitoring, and labour compensation in other cases. However, most of the funding agencies provided short-term support (initial establishment phase) except a few cases where support extended to monitoring phases of mangrove project implementation.

4.2 Discussion

4.2.1 Extent of mangrove reforestation effort in Kenya

Trial restoration projects were initiated in Gazi Bay of Kwale County in 1991 (Kairo *et al.*, 2001). The initiative got momentum from 1994, with the community participating in the reforestation of vast degraded mangrove sites of Gazi (Kairo, 1995b, Kairo *et al.*, 2001). Approximately 93.5 hectares of mangrove forests have been replanted in the 19 project areas along the coast. This indicates that mangrove restoration in Kenya is on small scale. In comparison, restoration activities in Kenya concentrated on the reforestation of small degraded patches within the existing forests across the intertidal zones. The high number of plantings in the mid intertidal zones can be attributed to highly degraded mangrove sites dominated by *Rhizophora mucronata* and *Ceriops tagal* which are the most targeted species for harvesting by local communities (GoK, 2017a). Similarly, the mangroves of Mombasa are the most degraded with up to 80% of its mangroves lost in other areas (Bosire *et al.*, 2014). This signifies a large potential area for restoration that resulted in high number of planting efforts as compared to Tana River and Lamu.

Mangrove restoration through planting has been dominated by the use of single or few convenient species in different parts of the world (Primavera and Esteban, 2008; Wodehouse and Rayment, 2019; Lee *et al.,* 2019). In Kenya, the two mangrove species; *R. mucronata* and *C. tagal* were the most preferred for reforestation activities. This is attributed to their large and long propagules which were found to be readily available and easy to plant. Further, the two species can be installed directly in the designated restoration site. Gazi system recorded the highest number of species planted compared to other sites. This is attributed to long-term practice and propagation of different types of species with the support of technical experts from KMFRI station located at Gazi bay. In addition, *R. mucronata* and *C. tagal* constitute 70% formation of mangrove formation in Kenya (Kirui *et al.*, 2013; GoK, 2017a). A study in the Philippines shows that there has been a widespread practice of planting *Rhizophora* species that resulted in the establishment of mono-specific stand by the surviving trees (Samson and Rollon, 2008). However, mono-stands have been considered to be poor in terms of biological diversity and simplification of the ecosystem (Lewis, 2005; Asaeda *et al.*, 2016).

4.2.2 Growth performance of replanted mangroves

This study presents mixed results of both failure and success following mangrove replanting activities. The choice of topographical positions – species selection and site mismatch were among the major causes that led to no or low survival rates of mangrove planting efforts. For example, some planting efforts in Jimbo and Kiwegu showed no surviving plants due to mangrove planting on the wrong sites (sandflats) at high intertidal zones (Fig 7a). This is consistent with major factors found in Philippines which led to massive failures of rehabilitation projects across the country (Primavera and Esteban, 2008). More often, lack or inadequate knowledge on species autecology has been the root cause of failure. In Sri Lanka, it is reported that mangroves planted on sandflats on high intertidal zones suffered from high salinity, irradiation and prolonged dry periods hence accelerating their mortality (Kodikara *et al.,* 2017). Similar to this study, failures of plantations at low intertidal zones are attributed to algae bloom, debris accumulation, and barnacle encrustation as observed in Gazi and Kiunga (Fig 7b and c). Failures in seaward sides have been also exacerbated by prolonged periods of flooding as observed in Philippines (Samson and Rollon, 2008).

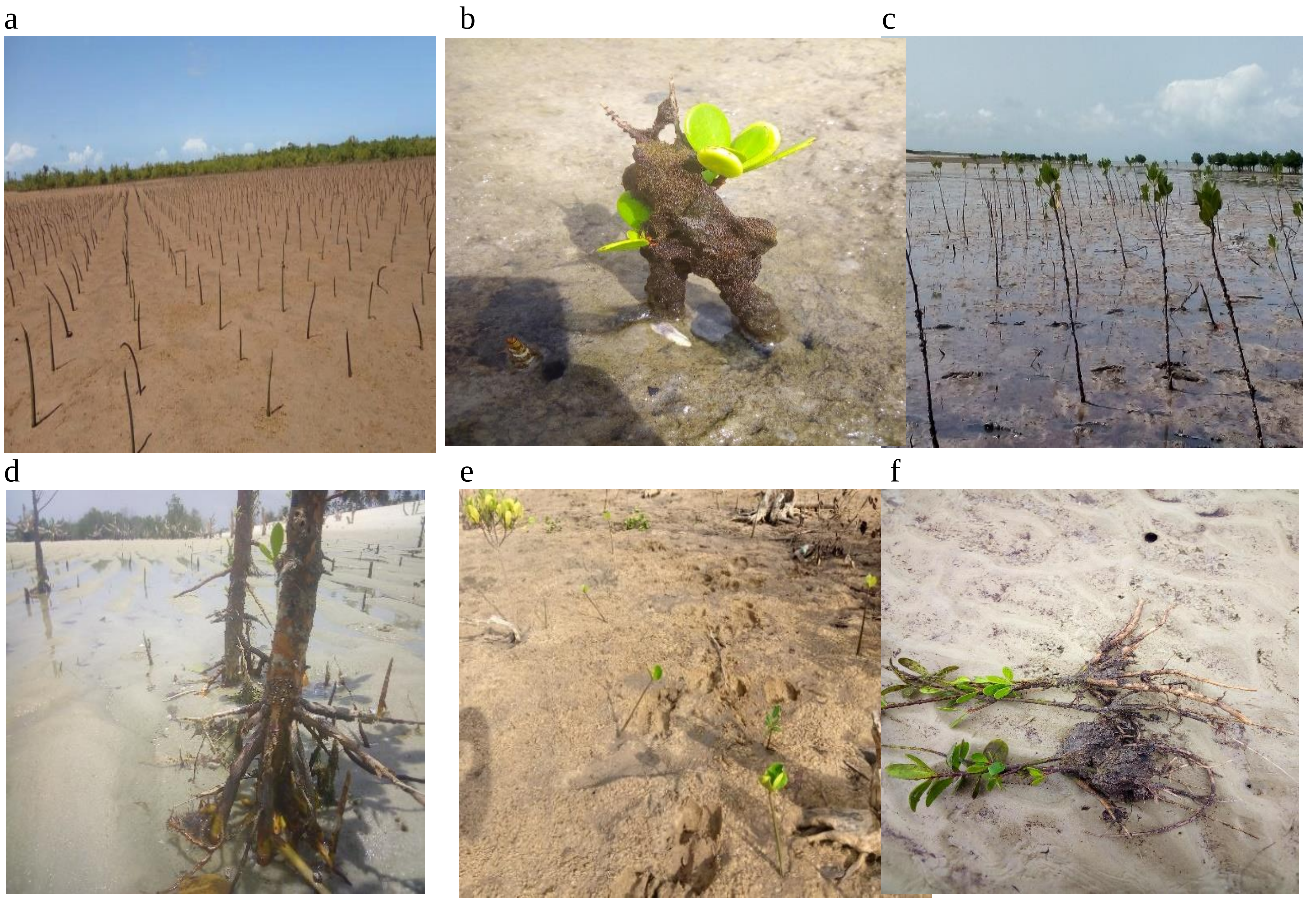

Figure 7: Examples of mangrove reforestation failures: (a) Mangrove propagules planted in wrong topographical position; (b) algal accumulation on replanted saplings; (c) barnacle infestation due to long period of submergence; (d) effects of coastal erosion and sedimentation expose tree roots leading to their death; (e)browsing and trampling by livestock; (f) root ball disturbance during transplanting.

Physical challenges have also been reported especially in the restoration of unshielded coastlines prone to wave action (Kamali and Hashim, 2011; Schmitt and Duke, 2015). This was similar to observed challenges which resulted in low survival rates of replanted mangroves particularly in Gazi bay (Fig 7d). Strong waves coupled with debris deposition, erosion, and change in sedimentation patterns alter hydrological regimes thus affecting the ecohydrological conditions. In Mekong Delta, Vietnam, the construction of cross-shore barriers (breakwaters) was done to reduce the wave energy and erosion to ease restoration after a poor performance during the initial stages (Schimitt and Duke, 2015).

Browsing and trampling by free-moving livestock (cattle) were among the major challenges to the achievement of short and long-term goals, as observed in plantations of Faza and Jomvu Kuu (Fig 7e). Similarly, this was a common factor across most projects in Sri Lanka that led to low survival rates of replanted mangroves countrywide (Kodikara *et al.,* 2017). Inappropriate trans-planting techniques have also compounded the causes of failures of restoration activities (Kairo *et al.,* 2001). For example, one of the planting activities witnessed in Gazi saw poor handling of seedlings (root-ball disturbance) thus likely to be a contributing factor to grave results (Fig 7f).

Generally, poor survival rates have been observed in different regions globally. In comparison to other regions, this study presents better performance. For example, 11 out of 19 project sites recorded survival rates higher than 50% in this study compared to Sri Lanka where only 3 out of 23 project sites had survival rates higher than 50% (Kodikara *et al.*, 2017). In addition, the mean survival rate recorded across all the project sites is 55.4±31.2% is quite higher than that of Philippines and Thailand that recorded average survival of 10-20 % (Primavera and Esteban, 2008; Wodehouse and Rayment, 2019). In order to avert future failures, Lewis (2000, 2005, 2009) emphasizes the need for ecological assessment to correct the site conditions such as ecohydrology, rather than “garden planting” of mangroves. The application of ecological principles restoration is a better approach to enhance restoration success (Brown and Lewis, 2006; Lewis *et al.,* 2019). Generally, the success of a replanted mangroves in terms of survival rates has been recommended at 85% and regarded as best to enhance long-term success and recovery of ecosystem functionality (Bayraktarov *et al.,* 2016).

Structural indicators (tree diameter, height, and biomass) during the development or building phase of replanted mangroves varied significantly ($p < 0.05$) within and among the species. Mean annual increments in height and diameter for 5 – 24 - year-old plantations ranged from 0.11 – 0.57 m/yr and 0.12 – 0.52 cm/year respectively. Based on the growth data available, Kairo *et al.,* (2008) found that the MAI in height and diameter of Rhizophora plantation at 12 years was 0.71m/yr and 0.53 cm/yr. At 24 years, the same plantations had a MAI of 0.57m/yr and 0.47cm/yr in height and diameter, respectively. This increment translated to a canopy height of 13.68±2.23 m (range: 6 – 18) with a stem diameter of 11.34±1.19 cm (range: 3.6 – 19cm). This data is within the range of 25 yrs. old *R. apiculata* plantation in Papua (Indonesia) that recorded a MAI of 0.69m/yr and 0.46cm/yr in height and diameter respectively. On the other hand, *S. alba* species recorded the highest MAI in diameter (0.52 cm/yr) akin to 22 – 29-year-old *Sonneratia apelata* plantations in Bangladesh which recorded MAI of 0.81cm/yr that was significantly higher than other species (Uddin *et al.,* 2014). In comparison with other species, low growth rates in *Ceriops tagal* species is also similar to *Ceriops decandra* of Bangladesh (Uddin *et al.,* 2014). While growth rates vary in accordance with species, earlier studies have suggested that the growth rates in parameters are expected to decrease as the plantation becomes old (Putz and Chan, 1986; Bosire *et al.,* 2008). Furthermore, growth performance may vary depending on the site conditions, age of plantation, and silvicultural practices (Bosire *et al.,* 2008; Uddin *et al.,* 2014; Phan *et al.,* 2019).

Stocking rates of 5 – 24 yr plantations ranged from 3575 – 7825 trees per hectare. This is within the range of 1,430 and 10,000 trees found in 4 – 26 -year-old plantations of *R. apiculata* in Vietnam (Phan *et al.,* 2019). In contrast, a study in Bangladesh reported a low stem density of 1087 – 1880 stems/ha for 22 – 29-year-old plantations (Uddin *et al.,* 2014). Stocking density difference in plantations is attributed to silvicultural practices such as initial planting intensities, thinning, and age of the plantation. For instance, this study recorded a stocking rate of 3625 stems ha^{-1} in a 24-year-old *Rhizophora* plantation in Gazi bay; that was 4864 stems/ha at 12 years (Kairo *et al.,* 2008). Self-thinning in mangroves is a common phenomenon (Pranchai, 2017), but for the plantations in Gazi, periodic thinning has been carried out to promote girth increment (Kairo *et al.,* 2008; Bosire *et al.,* 2008).

The biomass accumulation rate for 5 – 24-year-old plantations ranged from 1.14 – 15.67t/ha/yr. A 24-year-old Rhizophora plantation had the highest accumulation rate of 15.67t/ha/yr. This value is slightly higher compared to 12 t/ha/year when the plantation was 12 years old (Kairo *et al.,* 2008). On a contrary, 14-year-old *Rhizophora* in Jimbo recorded the lowest biomass accumulation of 1.14 t/ha/year. A study in Malaysia found a biomass increment of 5.1 t/ha/yr for an 80-year-old natural plantation of *R. apiculata* (Putz and Chan, 1986) which is significantly lower than the 20-year-old plantation in Matang forest which had 24.5 t/ha/yr (Ong *et al.,* 1995). Importantly, it reported that the rate of biomass accumulation decreases with the maturity of trees. Therefore, it is logical to conclude that forest growth parameters are influenced by age, species, site condition, silvicultural management practices as well as climatic variabilities (Bosire *et al.,* 2008).

Regarding the pattern of natural regeneration, the recruitment of juveniles varied significantly in density per hectare among the plantations. This suggests that replanting of mangroves has modified the site conditions to facilitate and allow the establishment of propagules. For instance, the 18-year-old *R. mucronata* plantation in Gazi had the highest juvenile density of 7150 per hectare as compared to the 14-year *S. alba* plantation which had 175ha per hectare (Table 8). Earlier studies have confirmed the recruitment of juveniles into the restored mangrove of Gazi bay (Bosire *et al.,* 2003; Kairo *et al.,* 2008). In the case of a 24-year-old Rhizophora plantation in Gazi, the study found a juvenile density of 1225 per hectare compared to 4886 saplings when the plantation was 12 years of age (Kairo *et al.,* 2008). These suggest that the number of recruited saplings has reduced with age. In Bangladesh Uddin *et al.,* (2014) recorded a regeneration density of 170 – 3462 saplings per ha for 22 – 29-year-old plantations, and 3183 – 10676 saplings/ha for 5 – 25-year-old plantations in West Papua, India (Sillanpaa *et al.,* 2017). While the study recorded a low regeneration ratio of the class structure compared to a rapid regeneration in a natural forest, low densities could be attributed to site conditions, propagule limitation predation by crabs as well as shedding effects (Lewis, 2005; Bosire *et al.,* 2006; Kairo *et al.,* 2008).

Mangrove-associated fauna (crabs and molluscs) plays a critical role in the functionality of an ecosystem thus provides an early indicator of change (Cannicci *et al.,* 2008; Nagelkerken *et al.,* 2008). In contrary to the loss of benthic diversity as a result of mangrove degradation (Carugati *et al.,* 2018), preservation and restoration of mangroves have proven to have a positive impact on the return of the diverse groups of macrobenthic invertebrates (crabs and mollusks) as observed in this study. For instance, *Perisesarma and Neosarmatium* species dominated across Rhizophora plantations akin to *Littoraria* and *Cerithidea* (Table 9). While the number and species of molluscs and crabs varied within and across plantations of different species, there were key species that were common within a given range. Additionally, variation in species evenness and diversity in relation to the age of mangrove plantations could be attributed to environmental settings and changes in site conditions. Past studies have shown that mangrove reforestation supports the recruitment of macrofauna to numbers similar or even higher compared to reference natural sites (Macintosh *et al.,* 2002; Bosire *et al.,* 2014). Generally, variation in diversity and species distribution is attributed to the type of mangrove species, inundation class, and soil factors along the gradient (Richmond, 2011).

4.2.3 Community perception of mangrove restoration practices

A review of secondary information on the objectives of mangrove conservation programs in Kenya indicates that their major role is to reclaim back the ecosystem's integrity and functionality. This is highly tied with the promotion of IGAs (e.g beekeeping and ecotourism) to bolster community sources of livelihoods as well as supporting community projects for development. This is in line with the global call to action for mangrove conservation and management for the benefit of people and nature (UNEP, 2014). Past studies have shown that the return of mangrove ecosystem integrity has the potential to increase fisheries and biodiversity conservation, shoreline protection, and climate mitigation (Walters *et al.,* 2000; Amhed *et al.,* 2017; Menendez *et al.,* 2020). While this study has highlighted several ecological objectives of mangrove programs, Ellison’s (2000) review found that earlier mangrove restoration programs had focused mainly on economic importance (Saenger, 2003).

Community willingness to participate in conservation and restoration activities may vary regionally. For instance, the major motivating factors in this study are ecosystem conservation and protection as well as incentives (financial compensation). Explicitly, the local communities have appreciated the ecological benefits such as shoreline protection and biodiversity conservation. This is inherent to the community's ethical imperative for nature conservation and protection for the benefit of present and future generations. Additionally, the provision of economic incentives and alternative sources of livelihood increases community willingness of buying the idea to participate in conservation and restoration. This is similar to findings by Melana *et al.,* (2000) that “people first and sustainable forest management will follow”. In this setting, the communities may not be motivated by ecological drivers alone but also financial compensation. Aheto *et al.,* (2016) argue that community livelihoods and economic paybacks were among the main factors that motivated the community in Volta estuary, Ghana. This is contrary to the case of Sri Lanka where mass planting of mangroves was triggered and motivated by the urgent need for coastal protection after the 2004 Tsunami that destroyed mangroves and led to the loss of lives in the region (Kodikara *et al.,* 2017). However, sustainability of restoration programs can be boosted through PES schemes which provide incentives as well as alternative sources of livelihoods (Pendleton *et al.,* 2012; Locatelli *et al.,* 2014).

A multidisciplinary approach to mangrove conservation has been advocated by both governments, academia, and civil societies over the past years (Datta *et al.,* 2012). From this study, it is clear that Kenya is putting more effort to embrace concerted efforts in mangrove conservation, restoration, and management. The Forest Act, (2016) stipulates the need to involve the public in forest management, particularly the adjacent communities. The involvement of key stakeholders including technical experts and adjacent communities is of critical importance to the success of conservation and restoration programs. In Indonesia, for instance, the failure of the mangrove projects was linked to ignorance of local politics and weak research (Dharmawan *et al.,* 2016). In this case, the local community should take control of mangrove conservation and rehabilitation practices. A case example of Mikoko Pamoja community-based organization that implements and manages replanted mangrove areas with minimal dependence on the external partners (Locatelli *et al.,* 2014). Despite the challenges highlighted in this study, it is prospected that sustainability and conservation of mangrove resources in Kenya can be achieved through integrated management that supports restoration and sustainable utilization thus contribute to the national and the global priorities of the UN decade.

CHAPTER FIVE: SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

5.1 Summary of key findings

This study identified and mapped 19 project areas in Kwale, Mombasa, Tana River, and Lamu counties where mangrove reforestation projects have been initiated. To date, less than 100 ha of mangroves have been rehabilitated through artificial regeneration; which indicates that the output is still quite low. This was attributed to the fact that restoration activities in the project areas were on small scale. In addition, mixed results based on survival rates of plantations ranged from 0 – 97.8% (mean 55.4±31.2%) is another factor. *Rhizophora mucronata* (52%) was the most preferred mangrove species for planting followed by *C. tagal* (28%), *A. marina* (9%), *B. gymnorrhiza* (7%) and *S. alba* (4%). This is because of their large and long propagules which were found to be readily available and easy to be handled with much convenience.

Structural attributes (height, diameter, stand density, and biomass) of the surviving plantations varied significantly due to species type, age, site conditions, and management practices. For instance, the study found that the MAI for 5 – 24-year-old plantations ranged from 0.11 – 0.57m/yr and 0.12 – 0.52cm/yr for height and diameter respectively. In addition, stand density and biomass ranged from 3575 – 7825 stems/ha and 14.0 – 375.9 t/ha respectively. It was estimated that the recruitment of non-planted species ranged between 175 – 7150 saplings per ha. Given that this determines the plant succession; the structure class ratio was lower compared to a natural forest with a rapid regeneration. Shedding, propagule predation by crabs, and ecosystem dynamic nature have been cited to limit rooting and establishment of abundant seedlings. On the other hand, macrofauna (crabs and mollusks) diversity index (H) between 1.60 – 1.87 is a clear indication that mangrove restoration encourages the return of diverse communities of benthic macrofauna.

Poor survival and dismal growth performance of replanted mangroves can be attributed to key ecological thresholds which led to wrong choices of the topographic positions, incompatibility with species selection, and change in site conditions. In addition, other biophysical disturbances included, wave action, debris deposition, barnacle infestation, and livestock browsing and trampling. On the other hand, successful practices were attributed to the availability of technical knowledge on species autecology and topography which saw the application of best practices. Additionally, proper institutional arrangements in some instances allowed participation of other stakeholders (mixed approach) thus played a critical role in post-care and monitoring of replanted mangroves. While the motivation to plant mangroves was driven by ecological and economic benefits as the major factors, conservation and restoration success could be boosted through the establishment of PES schemes and other price-based instruments as community incentives to ensure sustainability.

5.2 Conclusion

The study established that mangrove reforestation in Kenya is on a small scale when compared to similar initiatives e.g. South and Southeast Asia where thousands of hectares have been replanted and restored (Worthington and Spalding, 2018). While the study presents mixed results of both success and failures, only single or few species were mainly used for planting with *Rhizophora mucronata* dominating as the major species used for planting due to its ease of handling and planting. Causes of failures can be attributed to site selection and species mismatch, change in site conditions, while successful projects saw the application of best restoration practices as well as good governance. Consequently, the surviving plants showed variation in community structure as attributed to age, type of species, and environmental settings.

On the other hand, ecological and economic incentives were the major drivers of community participation in mangrove restoration practices. This simply means community welfare comes first the sustainable forest management will follow. Therefore, to enhance future mangrove restoration success and sustainability, integrating economic benefits through price-based instruments such as carbon credits and PES schemes as well as concerted efforts by different stakeholders is fundamental in the success of conservation and restoration activities.

To leverage on opportunities and existing potential to restore 3,351 ha of mangroves in Kenya (Worthington and Spalding, 2018), artificial regeneration alone will not be enough. For this reason, natural regeneration could play an additional crucial role in reversing the degraded conditions of mangroves. This is underpinned by the integration of all relevant stakeholders and more importantly, the community's willingness to participate in the conservation and protection of existing mangrove forests against any form of anthropogenic disturbances. The UN decade goal to prevent, halt, and reverse ecosystem degradation is imperative, and to promote and sustain conservation and restoration, efforts are required to overcome social-political hurdles and weak institutional arrangements. Apart from mainstreaming restoration policies into national programs and plans, payment of ecosystem services could be used to incentivize and support mangrove conservation and restoration. In turn, this will sustainably supply goods and services for local livelihoods and national economic development, accelerate the achievement of the Paris Agreement, and possible realization of SDGs – the Agenda 2030.

5.3 Recommendations

To enhance successful restoration and management of mangroves in Kenya, the following measures and recommendations are made:

5.3.1 Research recommendations

i. Promote propagation and establishment of mixed mangrove species where possible to reduce preference of single species as well as site selection and species mismatch during plantation establishments,
ii. Promote the application of Ecological Mangrove Restoration (EMR) principles rather than conventional planting methods,
iii. Local communities should be capacitated with mangrove restoration skills through education and awareness in order to develop a community of mangrove restoration practitioners,
iv. Need for regular and long-term monitoring to track the performance of the mangrove restoration project. Citizen science can play a key role where communities are equipped with knowledge and skills of data collection and monitoring,
v. Need to intensify studies on replanted mangroves since various studies have also focused on faunal recruitment,

5.3.2 Policy recommendations

i. There is a need to strengthen collaboration between government agencies, NGOs, private entities, and local communities,
ii. Incorporate monitoring and evaluation of mangrove restoration programs into the project implementation plans,
iii. Lead government agencies (KFS, KEFRI, KMFRI) should invest in training mangrove extension officers and provide technical and financial support to local communities,

iv. Success criteria should be designed before the initiation of any restoration program to provide a good basis for evaluation and the measure of success. This includes measurable objectives and goals,

v. Successful mangrove restoration and management need to be supported by the right economic benefits and incentives, such as PES schemes to increase community willingness to participate as well as long term sustainability,

vi. Create an ethical imperative of mangrove conservation and restoration as an obligation to the public through the creation of awareness on the importance of mangrove forests and the effects of their losses.

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APPENDICES

Appendix I: Mangrove Stakeholders

Governmental Agencies	Non-governmental organizations	Community Groups/CBO
Coastal Development Authority	Citi bank,	Bigship CBO
Kenya Forest Research Institute	Community Development Trust Fund	Brain Youth Group
Kenya Forest Service and the county governments	Earthwatch	Chara CFA
Kenya Maine and Fisheries Research Institute	East Africa Wildlife,	Community Touch Kenya (Com-touch)
Kenya Ports Authority	Ecosystem Services for Poverty Alleviation	Eco-talent Platform Group
Kenya Wildlife Service	Flora and Fauna International	Kiunga Community Conservancy.
National Environmental and Management Agency	Indian Ocean Commission	Lamu Muungano CFA
United Nations Development Program	International Coral Reef Initiative	Lower Tana Delta Conservancy
	Kenya Coastal Development Programme	Mikoko Pamoja CBO
	Mombasa Port Development Project	Mkupe Beach Management Unit
	Northern Rangeland Trust	Mkupe Mangrove Conservation Group
	Pamoja Trust	Mombasa Kilindini CFA
	Seacology	Pate Marine Community Conservancy
	The Nature Conservancy	Vanga Kiwegu Jimbo CFA
	World Vision Kenya- Changamwe IPA	
	World Wide Fund for Nature	

Appendix II: Vegetation survey data sheet

Structural assessment of replanted mangroves
Vegetation data sheet

Observer……………………………..…. Date……………………………. ……………………..
Area……………………………….…Forest type………………………...Plot no…………...
Plot size……………………………....Inundation class…………………...Cover (%) ……….
Age………………………………..… Total planted……………………...Surviving………....
No of Cuts……………………………No of Stumps………………………………………..
Southings……………………………..Eastings………………………………………………..

Tree no	Species name	Sub-species	Point of measurement (cm)	Diameter (cm)	Height (m)	Quality	Status

Secondary Succession

No	Mangrove species	RC I	RC II	RC III	Total		Faunal species	No of female	No of male	Total
1										
2										
3										

General observation…………………………………………………………………………

Appendix III: Individual survey questionnaire

Individual survey questionnaire

Consent

My name is………………… a student from the University of Nairobi/KMFRI. I am carrying out a research to *assess the effectiveness of mangrove reforestation projects along the Kenyan coast.* I am therefore going to ask you questions relating to mangrove restoration practices. I would kindly request you to allocate some of your time to help me respond to questions on the same. The information that you provide for this study is only for academic purposes and will be treated with confidentiality.

GPS Location Eastings………… Northings ……

Area……………….. Site ………………. Date…………

SECTION A

Socio-demographic information

No	Question	Answer
1.	Name …………………………………..	
2.	Gender of respondent 1. Male 2. Female	
3.	Age of respondent (years) a) Below 20 b) 21-30, c) 31-40, d) 41-50, e) Above 51 years	
4.	Marital status 1. Single 2. Married 3. Divorced 4. Separated 5. Others (specify)	
5.	Your highest level of education 1. Complete primary 2. Incomplete primary 3. Complete secondary 4. Incomplete secondary 5. Tertiary 6. Madrasa	
6.	Occupation 1. House wife 2. Farmer 3. Daily wage labor 4. Formal employment 5. Fishing 6. Business 7. Student 8. Others (specify)………………….	

SECTION B

Attitude and perceptions of mangrove restoration practices

7	Are there mangrove restoration programs in your area? a) Yes b) No	
8	What is the name of the restoration initiative/group you are involved in mangrove restoration?	
9	What is the objective of the project/initiative?	

	i. Environmental conservation ii. Community development iii. Climate change mitigation iv. Legislation compliance	
10	What motivated you to get involved in mangrove restoration and conservation projects? i. Daily wage ii. Environmental protection iii. Wood products iv. Fisheries v. Community development vi. Others (Specify)……………………………..	
11	Do you think mangrove restoration is an easy task? 1)Yes 2) No	
12	Give reason for the above answer ………………………………………………………………………….	
13	Mangrove restoration has presented a mixed bag of success or failure. What are factors that have contributed to success? i. Expert knowledge ii. Monitoring iii. Community participation iv. Good management v. Others (Specify)…………………………………………….	
14	What factors might have contributed to restoration failure? i. Change in site conditions ii. Inadequate knowledge iii. Predation/attacks iv. No post care/monitoring v. Others (Specify)……………………………………………	
15	What factors do you think might have affected the long-term success of restoration projects? a) Illegal harvesting b) Lack of community participation c) Weak institutions d) Inadequate finance e) Others (Specify)……………………………….	
16	What measures can be put in place to enhance the success of mangrove reforestation practices? ……………………………………………………	
17	What are your prospects/expectations do you think mangrove restoration project will achieve in the coming years…………………………………………………	

Asante sana! *Thank you for your time of participation*

Appendix V: Key informant interview questionnaire

Guide for Key Informant Interviews

<u>Consent</u>

My name is………………… from the University of Nairobi/Kenya Marine and Fisheries Resource Institute. I am carrying out a research to *assess the effectiveness of mangrove reforestation projects along the Kenyan coast.* I am therefore going to ask you questions relating to mangrove restoration practices. I would kindly request you to allocate some of your time to help me respond to questions on the same. The information that you provide for this study is only for academic purposes and will be treated with confidentiality.

Name…………………………Institution ……………. Position……………………..

GPS Location………………...Eastings…..………………Northings…………………...

Area…………………………..Site …………………….. Date…………………………

Contact………………………..

Leading questions

1. Do you have mangrove restoration practices in your area?
2. What is the name of the participating group/organization/association?
3. What are the objectives of the mangrove restoration program?
4. Do you have a place of community participation? What is the degree of participation?
5. Community participation is the key component in mangrove restoration. What do you think is their motivation /demotivation?
6. What are the major challenges encountered in mangrove restoration practices? (specific factors that have contributed to success or failure)
7. In order to enhance success in restoration practices, what measures do you think can be adjusted to improve performance?
8. Do you have restoration monitoring plans?
9. Which agencies/funders/partners have you involved in planting initiatives?
10. What are your prospects on mangrove restoration projects in the coming future?

Thanks for your time.