Assessing the potential for voluntary carbon markets to contribute to sustainable conservation at the Manda Island Conservancy Project, Kenya

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This project is part of the Oppenheimer Programme in African Landscape Systems (OPALS) at the University of Exeter.

"I certify that this dissertation is entirely my own work and no part of it has been submitted for a degree or other qualification in this or another institution. I also certify that I have not collected data nor shared data with another candidate at Exeter University or elsewhere without specific authorisation."

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Abbreviations

Abbreviations	
CCM	Compliance Carbon Market
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
COP27	The 27th Conference of the Parties
CSV	Comma Separated Value
FAO	Food and Agricultural Organisation
GHG	Green House Gases
GMW	Global Mangrove Watch
GoK	Government of Kenya
Ha	Hectares
IPCC	Intergovernmental Panel on Climate Change
JAXA	Japan Aerospace Exploration Agency
KFS	Kenya Forestry Service
MICP	Manda Island Conservancy Project
Mg C	A tonne of carbon dioxide
NbS	Nature Based Solution
NGO	Non-Governmental Organisation
PES	Payment for Ecosystem Services
QGIS	Quantum Geographic Information System
REDD+	Reduced Emissions from Deforestation and Degradation
SAR	Synthetic Aperture Radar
SDG	Sustainable Development Goal
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
VCM	Voluntary Carbon Market
WWF	World Wide Fund for Nature
$	United States Dollar

Table 1: Abbreviations

Abstract

The development and implementation of blue carbon projects around the world is increasingly driven by climate-related pressures. This dissertation analyses whether the mangroves found within the Manda Island Conservancy Project (MICP) in Kenya, could form the basis of a blue carbon project. Remote sensing data is used to determine mangrove cover, produce a time-series of mangrove cover change and estimate the total ecosystem carbon stock of the MICP mangroves. Between 1996 and 2020 a net increase of 5 hectares (ha) to 169 ha is observed. The total ecosystem carbon stock as of 2020 is estimated at 525.36 Mg C ha^{-1}. Analysis indicates that that the carbon stock is sufficient to provide an annual income of $17,238 through the voluntary carbon markets which can be used to sustainably manage the MICP landscape. These observations are used to inform recommendations for the MICP which highlights the potential for a commercially viable carbon project, but also identifies areas requiring further evaluation, including conducting a full economic assessment, understanding the new Kenyan regulation and undertaking fieldwork to verify the estimations in this paper.

Extended Summary for Manda Island Conservancy Project Stakeholders

The Manda Island Conservancy Project, which encompasses parts of Manda Island and the neighbouring Manda Toto Island, lies within the Lamu Archipelago off the north-eastern coast of Kenya. The project is in the process of developing a wildlife conservancy, aiming to protect and restore the surrounding ecosystems. To achieve this outcome, the MICP needs to better understand whether the mangroves found within the conservancy could form the basis of a successful carbon project, providing an income stream to aid sustainable management of the landscape. The practice of carbon offsetting has been developing for decades but has only recently expanded to include marine ecosystems under the banner of blue carbon. Blue carbon projects include species such as mangroves and seagrass due to their intertidal ecosystems and proximity to marine life.

The aims of this dissertation project are fivefold: (1) to evaluate and understand how much carbon is currently stored within the MICP mangroves; (2) to analyse trends in the MICP mangrove coverage over time; (3) to understand the extent to which the mangroves could provide carbon finance to contribute to sustainable conservation; (4) to set out recommendations on how the mangroves could support socially and ecologically sustainable management of the landscape, and (5) to highlight areas which should be prioritised for future work in this field.

Three prominent gaps in the existing literature were identified. Firstly, the quantification of mangrove coverage and carbon sequestration is predominantly published at global and state levels, highlighting the need for more specific and localised analysis for projects wanting to enter the carbon market. Secondly, the constant shifts in carbon markets including baseline setting and regulatory frameworks create barriers for small projects such as the MICP to assess the viability of their projects. Finally, as existing blue carbon mangrove projects are localised and site specific, there is a lack of existing literature and research pertaining to the mangroves found within the MICP boundaries and whether those mangroves would be able to form a carbon project.

To address the gaps in the literature and the research questions, this dissertation uses a quantitative methodology. Using data from the Global Mangrove Watch 3.0 dataset, mangrove cover across both the MICP and the wider Lamu County is calculated and evaluated over time. This analysis is done using Quantum Geographic Information System (QGIS) and RStudio. Calculations to determine the current carbon stock and provide estimations of earning potential from the carbon markets are undertaken and systems thinking is used to produce a systems dynamics model to highlight risks of mangrove degeneration and deforestation and provide recommendations on sustainable management of the landscape.

The results show that total mangrove cover within the MICP is estimated as 169 ha representing 16.9% of the total area. Above ground biomass carbon stock is estimated as 21,873.67 Mg C and total ecosystem carbon stock is estimated as 88,785.84 Mg C. Lamu County experienced an overall loss of 100 ha of mangrove cover, and the MICP experienced a gain of 5 ha of mangrove cover during the 24-year period of observation between 1996 and 2020. The decrease in mangrove numbers in Lamu County could be attributed to continued legal and illegal harvesting of mangroves, the construction of the Lamu Port and the 1997-98 El Niño rains which decimated large areas of mangrove cover. The increase in mangrove coverage in the MICP could be due to higher levels of protection around areas such as Manda Bay Hotel and the inaccessibility of Manda Toto.

Using the total ecosystem carbon stock estimation figure and the World Bank's 2022 average carbon credit price of $6.4 (USD) the total value of the MICP mangroves is estimated as $568,299. Using a comparison of the MICP to the successful Mikoko Pamoja mangrove project in Kenya, which covers a similar size area, and using their average sale price of $6 per tonne, an estimated annual income of $17,238 could be provided by the MICP mangroves. Registering new carbon projects, however, incurs upfront fees payable to the verification organisation overseeing the carbon credits and new regulation in Kenya is due to come into effect enforcing, among other things, a stipulation that 25% of aggregate earnings from carbon projects must be paid to local communities. Therefore, further economic assessment will need to be undertaken.

Considering the results from this research, the following recommendations should be considered by the MICP. First, fieldwork must be carried out across the area to validate the mangrove coverage and assess the full carbon stock, including carbon held within the soil. Particular attention must be paid to the areas where the dataset showed inaccuracies. Secondly, a full economic assessment should be done encompassing initialisation costs, associated fieldwork costs and payments due under the new Kenyan legislation once finalised. Thirdly, it is recommended that local community involvement is prioritised from the start. Finally, it is recommended that the MICP waits until the new Kenyan legislation and accompanying regulation has been passed before initiating a blue carbon project.

Overall, this dissertation project provides a thorough evaluation of the mangroves and their potential to form the basis of a blue carbon project within the MICP. It quantifies the baseline mangrove cover and carbon stock, explores the complex challenges facing mangrove conservation across Lamu County and highlights the multifaceted nature of the voluntary carbon markets and the steps required to create a successful project. The MICP can use these findings to make an informed decision on whether to initiate the formation of a blue carbon project to maximise the income potential of the mangroves to support conservation.

1. Introduction

Climate change is one of the most complex and consequential challenges facing humanity today. Over the last year, the world has experienced extreme heat, serious flooding and severe drought, with experts warning drastic reductions in emissions are required to avert some of most catastrophic impacts of global warming (IPCC, 2023; McLeod and Salm, 2006; World Bank, 2023). According to the Intergovernmental Science Policy Platform for Biodiversity and Ecosystem Services, global warming and anthropogenic influence have also put one million species under threat from extinction (Tollefson, 2019). It is imperative efforts to reduce emissions take centre stage for both nations and corporations across the globe.

The practice of carbon offsetting has developed over the last few decades as a tactic to help those emitting greenhouse gases (GHGs) limit their damage whilst decarbonising their activities. Carbon offsetting works on the principle that for every tonne of carbon, or carbon equivalent released into the atmosphere, a tonne is also removed from the atmosphere. As technologies such as direct carbon capture are years away from maturity, a popular way of offsetting emissions is through harnessing nature-based solutions (NbS) which involve natural processes in the earth's terrestrial and marine ecosystems. Nature-based solutions are activities centred around protection, conservation, sustainability and restoration of ecosystems, which also address environmental, social, and economic challenges whilst protecting ecosystem services (WWF, 2022). Seddon et al (2020) concludes that preserving the ecosystem services derived from nature whilst simultaneously protecting against climate change's impacts is at the heart of nature-based solutions. Projects designed as nature-based solutions within the carbon offsetting sector adopt a standard framework of trading carbon credits across the carbon credit market.

Carbon credits are units generated through voluntarily implemented emission reductions and are achieved through either the avoidance of emissions or by directly capturing carbon from the atmosphere and storing it (World Bank, 2023). The carbon market has developed over recent decades to become a vital tool which, according to the World Bank, must be used in conjunction with emission reductions to ensure states remain on track to limiting global warming. Whilst the nature of carbon offsetting seems promising, there remains controversy around the practice due to concerns around integrity, legislation and regulation (Lang et al., 2019). Until recently, natural climate solutions were almost entirely exclusive to green carbon (terrestrial) ecosystems and largely ignored the marine and coastal ecosystems which provide blue carbon opportunities (Macreadie et al., 2022). The registration of blue carbon projects which include mangroves has been steadily increasing across the globe. Mangrove ecosystems are popular and widely used across the world in NbS projects (Hespen et al., 2023) as they have amongst the highest carbon density of any tropical forest (Adame et al., 2021; Donato et al., 2011). Research suggests globally mangroves store a carbon equivalent of 22.86 gigatonnes of CO_2 (Leal and Spalding, 2022) and boast ecosystems that enhance biodiversity, provide coastal protection and are a core part of coastal livelihoods (UNEP, 2007). The carbon sequestration potential of mangroves, combined with the ecosystem services they provide, makes them of particular environmental and political importance (Adame et al., 2021; Macreadie et al., 2014). Despite this importance, many mangrove ecosystems across the world have suffered degradation due to both anthropogenic and natural pressures (Bosire et al., 2014; Kirui et al., 2013; Siikamäki et al., 2012), therefore reducing their co-benefits (Kairo et al., 2021).

The Kenyan coastline is peppered with mangrove ecosystems which according to official records represent 3% of the country's natural forest cover (GoK, 2017). The Lamu Archipelago, off the north-eastern coast of Kenya is home to the majority of the country's mangroves (County Government of Lamu, 2018; Kairo et al., 2021). In addition to their carbon sequestration potential, these ecosystems are recognised as biodiversity hotspots by the Kenyan government, providing habitats to several endemic species, acting as nursery grounds for fish and providing local communities with timber and shoreline erosion protection (Kairo et al., 2021; Kirui et al., 2013; Owuor et al., 2019). Within Lamu County lies the newly established Manda Island Conservancy Project, encompassing parts of Manda Island and the neighbouring Manda Toto Island. The MICP is currently in the process of creating a wildlife conservancy to protect and restore the surrounding unique marine and terrestrial forest ecosystems. It is working to build a wildlife conservancy that will protect the mangroves and restore wildlife populations. It also aims to build education and training facilities to increase local conservation awareness.

This dissertation seeks to quantify the coverage of mangroves within the MICP and calculate an estimation of the above ground biomass carbon and total ecosystem carbon held within the mangroves. It will also analyse how the mangrove cover has changed within the MICP and the wider Lamu County and provide recommendations on how mangroves can be used for sustainable management of the landscape. A literature review identifies gaps in the research, discusses the importance of mangroves, current carbon credit market frameworks, carbon projects and mangrove ecosystems in East Africa and Kenya, leading to the presentation of five research questions. The dissertation then uses the Global Mangrove Watch 3.0 dataset, QGIS and RStudio to quantify the MICP mangrove carbon stock and analyse trends over time. The results are used to inform recommendations for the MICP, ascertaining whether the mangroves would be viable as the basis for a blue carbon project and whether the mangroves and any carbon finance gained from them can be used to help the MICP sustainably manage the landscape.

2. Literature Review

2.1. The importance of mangroves

Mangrove forests are taxonomically diverse, salt-tolerant inter-tidal ecosystems of trees and shrubs that have evolved and adapted to live within warm tropical and subtropical areas with sufficient sediments which allow them to set down roots (Giri et al., 2011; Leal and Spalding, 2022; McLeod and Salm, 2006). Mangroves are able to both thrive and grow in saline environments and are distinguished from other species through their physiological and morphological adaptations, such as their aerial rooting system which during a 12-hour cycle is partly exposed to the atmosphere and then submerged in water at high tide (FAO, 2023).

Mangrove ecosystems are havens for coastal biodiversity, supporting fish, mammals and birds, exceptional at storing carbon and provide a host of ecosystem services to local communities including fishery nurseries, shoreline protection, fuelwood and timber (Donato et al., 2011; Leal and Spalding, 2022; Locatelli et al., 2014). As a core ecosystem component, mangroves tend not to exist in isolation, instead they thrive within tidal wetland systems which consist of variations of interconnected parts which continually interact through a series of feedback loops (Kirwan and Megonigal, 2013; Murray et al., 2022). These wetland systems often encompass nearby terrestrial, marine and freshwater habitats and these habitats are further influenced by a combination of marine, coastal and terrestrial processes and the links and relationships between them (Leal and Spalding, 2022; Murray et al., 2022). The interactions across the system work together to provide ecosystem services, making them important both for local coastal communities who depend on them and as an integral tool in climate change mitigation strategies.

Mangrove ecosystems make crucial contributions to many of the United Nations Sustainable Development Goals (SDGs) through the provision of their critical ecosystem services. Notably, they contribute to SDG 14 (Life Below Water), but also influence SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 13 (Climate Action) and SDG 15 (Life on Land) (FAO, 2023). Consequently, mangrove ecosystems are now viewed as of considerable global importance and are recognised at international levels. Recent policy advancements, such as the inclusion of coastal and ocean ecosystems in the Glasgow Climate Pact and the inclusion of mangroves into the 2022 UN Ocean Conference are now pressurising governments to create and implement frameworks to protect and restore mangroves on a global scale (Leal and Spalding, 2022). In addition to this the Bonn Challenge, the New York Declaration on Forests, the United Nations Decade on Ecosystem Restoration and national restoration targets including nationally determined contributions are building significant momentum globally on ecosystem restoration, which includes mangrove ecosystems (FAO, 2023).

Localised analysis also highlights the diverse ecosystem services provided by mangrove ecosystems. Modelling by the Global Mangrove Watch in 2020 estimated that 4.1 million fishers depend on mangroves, which support the production of almost 600 billion fish and shrimps and 100 billion bivalves and crabs (Leal and Spalding, 2022; Spalding and Leal, 2021; Zu Ermgassen et al., 2020). Furthermore, mangrove ecosystems have a vital role to play in protecting coastal communities from storms and coastal erosion, events which are likely to become more frequent and intense due to climate change (Spurrier et al., 2019). The ecosystems provide protection by reducing wind and swell waves, reducing tsunami heights, reducing erosion by building up soils and reducing flooding impacts (Spalding et al., 2014). Indeed, mangrove forests are now being used in coastal nature-based solution strategies as a sustainable and effective solution to reduce localised flood risks and are being incorporated into coastal flood protection plans to increase resilience (Hespen et al., 2023). It is important, however, to note that, whilst mangroves can help protect against some of these climate change induced events, they can also suffer increasing damage from them, as they are at greater risk as sea levels rise and the frequency and severity of storms increase (FAO, 2023).

Mangroves are also an important source of carbon storage. As with all vegetated systems across the globe, mangroves absorb carbon dioxide (CO_2) from the atmosphere through the process of photosynthesis. Part of this carbon is then stored within the living biomass of the mangroves, such as the roots, trunks and leaves, and part is stored in the soil forming soil organic carbon (Owuor et al., 2019; Spalding and Leal, 2021). Mangrove material undergoes a very slow decomposition process as the soil is constantly waterlogged due to the changing tides, therefore the carbon within the soil can take hundreds of thousands of years to accumulate. This makes them an impressive carbon sink. As a result of their unique waterlogged environments, mangroves are estimated to contain up to four times the amount of carbon per hectare compared to other forested ecosystems (Donato et al., 2011; Leal and Spalding, 2022), making them a sought after candidate for conservation projects and carbon markets. For comparison, the mangroves found within the Amazon rainforest are estimated to store over 500Mg C ha^{-1}, whereas their neighbouring rainforest ecosystems are estimated to store just under 300Mg C ha^{-1} (Kauffman et al., 2018). Worldwide, mangroves are estimated to store around 22.86 gigatonnes of carbon (Leal and Spalding, 2022; Macreadie et al., 2022; Sanderman et al., 2018) whereas, tropical rainforests are estimated to store over 250 gigatonnes of carbon, however they cover substantially more of the earth's surface (USDA, 2017). Losing just 1% of the world's remaining mangroves to deforestation or degradation could, therefore, lead to a substantial increase in emissions as the mangroves would turn from carbon sinks to carbon sources, releasing an amount of CO_2 into the atmosphere calculated as equivalent to over 520 million barrels of oil (Leal and Spalding, 2022) thus having a substantial impact on global warming. Therefore, mangrove restoration could be highly impactful, providing some of the world's highest carbon capture and storage related benefits.

Despite the global importance of mangroves, these ecosystems have been declining worldwide by millions of ha since 1990 (Figure 2.1). There is, however, some discrepancy amongst the estimations of global mangrove decline. Some estimates point to a global decline of up to 35% in mangrove cover from 1980 to 2000 (Hagger et al., 2022), whilst others highlight a continual annual decline of 1.3% over the past several decades (Goldberg et al., 2020). Conflicting conclusions have been drawn as to whether the loss has been countered by any gains, with Murray et al (2022) concluding that most losses of mangroves have not been substantially offset with any gains, while the UN Food and Agricultural Organisation (2023) concluded the opposite, citing natural expansion and conservation approaches having offset loss. Should the restoration of all mangroves become a priority, estimates suggest this would result in an additional draw down of 841Tg CO_2e per year by 2030, collectively amounting to 3% of global emissions (Macreadie et al., 2022). Whilst it is not feasible to restore all the world's lost mangroves, these calculations indicate how important mangrove protection and restoration is.

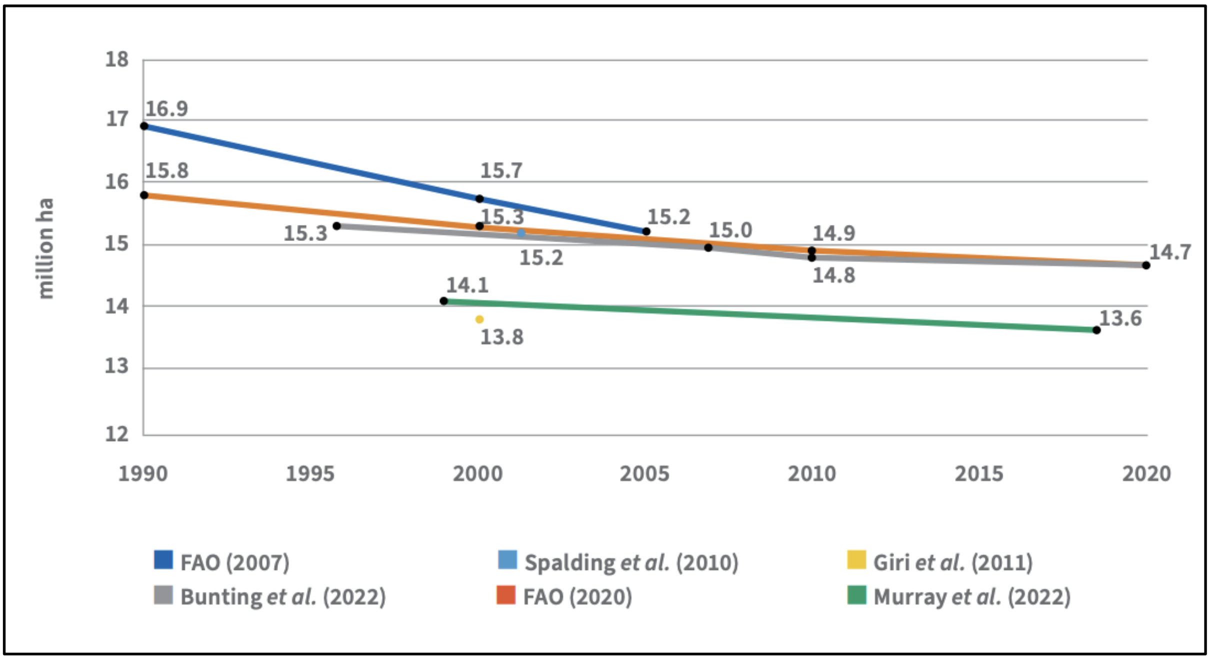

Figure 2.1. Graph highlighting the different estimations of global mangrove decline, compiled by the UN Food and Agricultural Organisation, 2023 *(FAO, 2023).* *Each paper presented here used slightly different methodologies, the Bunting et al. (2022) paper represents the dataset used in this dissertation.*

Mangrove decline is being caused by direct human impact and climate change, leading to significant ramifications for ecosystems. The decline in global mangroves can in part be attributed climate change as it impacts ecosystems in several ways leading to natural retraction. Specifically, sea-level and temperature rise, increases in extreme weather, changes in rainfall patterns and increases in atmospheric carbon dioxide all have effects on mangrove resilience (FAO, 2023). These in turn have a negative effect on the surrounding coastal communities. Despite this, 60% of mangrove loss worldwide is attributed to direct human impacts such as aquaculture, urbanisation and conversion of coastal land to agricultural land (Goldberg et al., 2020; Spalding and Leal, 2021). Fully understanding the extent to which mangrove cover is changing globally is becoming increasingly urgent due the disproportionate importance these ecosystems have in relation to biodiversity, climate and the provision of ecosystem services (Bunting et al., 2022a). Furthermore, despite mangrove forests only accounting for between

2% and 3% of the global forested system (Giri et al., 2011), their ecosystem services have attained values worth billions in USD (Jerath et al., 2016).

There remains some uncertainty around local and regional mangrove ecosystem degradation. In the last few years, due to the prominence of mangroves on the global stage and increased research into the importance of mangroves, there is some evidence to suggest overall human-driven decline of mangroves is stabilising and slightly abating (Goldberg et al., 2020). However, on a national level, human-driven decline of mangroves remains a problem in countries such as Kenya (Kairo et al., 2021), Indonesia (Ilman et al., 2016) and Brazil (Rovai et al., 2022). This highlights the need for continued efforts to understand and quantify localised sub-national mangrove coverage and carbon sequestration potential. Specific and localised analysis can then be used to increase the chances of success for grassroots conservation and restoration projects.

2.2. Carbon markets and mangrove ecosystems

The concept of carbon markets originated in the 1980s and started to mature a decade later in the 1990s when international bodies laid down foundations for the practice. The Kyoto Protocol established the first carbon market system in 1997 and the first iterations of the Compliance Carbon Market (CCM) and Voluntary Carbon Market (VCM) came into play shortly afterwards (Lang et al., 2019). The CCM services national governments and industry members required under an international treaty (such as the European Union Emissions Trading Scheme or the Kyoto Protocol) to reduce their emissions, whereas the VCM is open to any buyer and to date has largely been used by the private sector (Lang et al., 2019; Wylie et al., 2016).

Carbon markets are centred around the concept that carbon stored within terrestrial and marine ecosystems can be scientifically quantified and sold as carbon credits, which a buyer is able to use to offset their carbon emissions (Wylie et al., 2016). A carbon crediting mechanism is used to generate tradable certificates which represent emission reductions and the carbon price provides confidence for the markets, which allows markets, instead of governments, to determine where emissions could be reduced at the lowest possible cost (World Bank, 2023). A purchased carbon credit is classed as retired to ensure it cannot be bought twice. The current regulation for the verification of carbon credits requires that it must be done through an accredited third-party verification body such as Verra, Plan Vivo, Climate Action Reserve or The Gold Standard. For each new project, these organisations conduct additionality tests to determine a baseline for the project and ensure the carbon reductions go beyond a business-as-usual sequestration scenario. They also undertake processes which encompass monitoring, accounting, verification and certification standards, as well as certificate issuance (Lang et al., 2019; World Bank, 2023; Wylie et al., 2016).

The carbon market covers many forms of emission reduction tactics, yet over the past few years, there has been a focus on NbS within the carbon crediting space, with an emphasis on emission reductions from forestry and other land use activities (Hespen et al., 2023). In their study, Seddon et al (2021) highlighted that for NbS projects to have integrity and longevity, they must encompass four distinct pillars. Firstly, they must involve the conservation of existing ecosystems, including addressing human and societal challenges, secondly they must restore destroyed or degraded ecosystems, thirdly they require an emphasis on improved land management and resources and finally they should involve the creation of new ecosystems using processes such as afforestation. Credits generated by NbS often come with co-benefits such as ecosystem services which are valued by buyers. However, as each project is localised and falls under country specific regulation, they come with their own unique challenges (World Bank, 2023).

There are many voices arguing for continued use of NbS worldwide, highlighting that they are a vitally important step in the decarbonisation journey (Adame et al., 2021; Seddon et al., 2020). They have the potential to restore degraded ecosystems (Debrot et al., 2022) and provide an alternative income to local and indigenous communities (Seddon et al., 2021). They also provide ecosystem services which are valued the world over (Locatelli et al., 2014). A body of literature, however, also calls out controversy surrounding NbS and carbon credits, highlighting the negative impacts for local communities such as displacement and resource restrictions (Townsend et al., 2020) and the potential for NbS to offer a dangerous distraction from decarbonisation (Melanidis and Hagerman, 2022). Nature-based solutions have in some cases been co-opted for corporate greenwashing (Seddon et al., 2021), highlighting further challenges with integrity. Recently, there has also been prominent public criticism surrounding the transparency of some carbon credit projects and uncertainty around best-practice and baseline setting, which has led to one of the largest verification bodies Verra reviewing part of its independent crediting mechanism, with a new methodology set to be released imminently (World Bank, 2023). Uncertainty around baseline setting is one of the largest debates centred around carbon credits and NbS as there is no standard framework for projects, meaning baselines are often privately defined, frequently through the third party verifiers who have a vested interest in the projects, leading to concerns of manipulation and overestimation (Liu and Cui, 2017). Baseline setting determines the overall potential of the project, therefore, a miscalculation of a baseline could lead to a project underperforming or an overestimation of emission reduction levels. Indeed, a study recently concluded that methodologies used to construct baselines need urgent revisions if incentives for forest conservation and the integrity of global carbon accounting are to remain intact (West et al., 2023). There are also concerns around permanence and leakage, as conserving one area ay degrade another, and ensuring the longevity of these projects need strong management plans (Worthington et al., 2020). The criticisms around baseline setting, permanence and leakage are not new, however the recent increase in interest in carbon crediting coupled with these drawbacks highlights the importance of efforts to improve integrity and transparency.

There is growing interest in evaluating how mangroves could be included within NbS projects. This has been partially driven by the application of Verified Carbon Standard methodology for seagrass and tidal wetland restoration (VM0033), which has created an opportunity to use existing carbon financing systems such as payments for ecosystem services (PES) and Reduced Emissions from Deforestation and Degradation (REDD+) on an international scale (Locatelli et al., 2014; Macreadie et al., 2022; Mitra et al., 2022). REDD+ provides payments for emissions reductions achieved through the reduction of degradation and deforestation as well as improved forestry management (Atela et al., 2016), whereas PES provides payments for ecosystem services from the beneficiaries of those services to the communities who own the land and subsequent natural solutions that provide those services (Locatelli et al., 2014). In this context, and given mangroves offer the potential to sequester large amounts of carbon and increase biodiversity, they are becoming increasingly desired by customers trading on the VCM (Macreadie et al., 2022).

Mangroves are intertidal and integrated with wetlands and oceans, meaning they are increasingly being classed as blue carbon projects (Vanderklift et al., 2019). Blue carbon refers to the carbon captured and stored in marine and coastal ecosystems (Anand et al., 2020; Karani and Failler, 2020). To date, research on blue carbon ecosystems has mainly focused on assessing their ability to provide the starting point for conservation projects that aid climate change adaptation whilst providing the local communities with a host of ecosystem services (Karani and Failler, 2020; Mitra et al., 2022; Steven et al., 2019). Consequently, mangrove ecosystems have been classed as exceptional candidates for blue carbon projects. As all carbon and blue carbon projects are localised and site specific, individual initiatives such as the MICP face difficulties assessing the viability of their potential project given shifts in carbon markets, frameworks, and baseline setting. This is particularly true for possible blue carbon mangrove projects, given the relative infancy of the field.

2.3 Mangroves in Kenya and East Africa

The East African coast is a hotspot for mangrove ecosystems, with the mangroves found along and off the coastline accounting for 5% of global coverage (Hamza et al., 2020). These mangrove ecosystems have played an important role throughout East Africa's history, with the harvesting of mangrove poles becoming a major trade by the 19th century (Riungu et al., 2022). At the turn of the 20th century Kenya alone was exporting just shy of 500,000 poles annually, the majority of which were harvested in Lamu County (GoK, 2017). Under British colonial rule in 1947, the government implemented strict control of mangroves, ruling that only five firms could harvest poles in a deeply unpopular move which resulted in the illegal harvesting of mangroves, a trend that has continued until the present day (GoK, 2017).

Despite their historical prominence, mangrove ecosystems in East Africa have been part of the global decline. For instance, in Kenya there was a 20% reduction in mangrove cover between 1985 and 2010 equating to roughly 450 ha of mangrove loss per year due to natural and anthropogenic pressures (GoK, 2017; Kirui et al., 2013). The continuous deforestation of mangroves could be at least in part a consequence of the rapid population and economic growth East Africa has undergone in the last three decades because mangrove poles are often used to build homes (Riungu et al., 2022). Between 1990 and 2020, as the average life expectancy of those residing in East Africa jumped from 45 years to 67 years, forest cover decreased by 17% (Bullock et al., 2021). The same study highlighted that population growth rates across Sub-Saharan Africa are now among the highest in the world, which leads to increased pressure on land and subsequently land conservation, with a 34% increase in land conversion to cropland being recorded in East Africa between 1998 and 2017. This highlights population growth in areas where mangroves are prominent may result in their degradation.

Mangrove ecosystems across Kenya face serious threats with the main causes identified as increased population, high levels of poverty and lack of alternative livelihoods, weak governance, very few mangrove management systems, inadequate understanding of the value of mangrove ecosystems and how long the ecosystems would take to regenerate and adequately restore (GoK, 2017). Globally, the total number of mangrove species ranges from 50 to more than 70 (FAO, 2023). Of these, nine mangrove species have been identified across Kenya, *Rhizophora mucronata*, *Ceriops tagal* and *Avicennia marina* are dominant, while *Bruguiera gymnorrhiza*, *Heritiera littoralis*, *Lumnitzera racemose*, *Sonneratia alba*, *Xylocarpus granatum* and *Xylocarpus moluccensis* have also been identified (Hamza et al., 2022; Kairo et al., 2021). All nine of these species have been affected by mangrove harvesting in Kenya (Riungu et al., 2022). These losses are felt more acutely in rural areas and the communities hit the hardest are those that derive their livelihoods from the ecosystems (Hamza et al., 2022). The losses experienced due to this have widespread negative impacts on shoreline stability, availability of mangrove poles and fisheries (County Government of Lamu, 2018; Kairo et al., 2021). As the MICP sits within Lamu County, the mangrove degradation trends seen across this area will have affected the mangrove cover across the conservancy and it will face many of the same threats to its ecosystems.

Further degradation of East African mangrove ecosystems is likely to increase coastal hazard risk. A study focusing on East African coastal vulnerability highlighted that 22% of coastlines are already at risk from coastal hazards, but if mangroves, seagrass and coral reefs were to further degrade this would increase to 39%, affecting 6.9 million people (Ballesteros and Esteves, 2021). The same study found that mangrove degradation has left Madagascar and Mozambique with the highest coastal risk exposure, whereas Kenya and Tanzania currently benefit from more shoreline protection due to their mangrove cover. Currently only 16% of the Kenyan coastline is at a high level of exposure to coastal hazards, however this could increase to 41% if these blue carbon ecosystems are lost (Hamza et al., 2020). Whilst Kenya benefits more than other countries from its coastal ecosystems, it is consequently likely to experience the greatest impact should mangroves and coral reefs degrade (Ballesteros and Esteves, 2021) leading to coastal protection being considered one of the key ecosystem services provided by Kenyan mangroves (Hamza et al., 2020; Owuor et al., 2019). Therefore, mangroves such as the ones found in the MICP should be prioritised in coastal management projects.

2.4 Economic potential and livelihood impact of mangrove carbon projects in Kenya

In parallel with the rise in popularity of carbon credits, there has been a growing interest in implementing mangrove carbon projects based in Kenya. The most well-established and successful blue carbon mangrove project is called Mikoko Pamoja which can be found in Gazi Bay, southern Kenya. Funded and supported by the verification organisation Plan Vivo, the project has been highlighted as the first blue carbon project in the world to sell carbon credits on the voluntary carbon markets generated through the protection, restoration and management of their mangroves (Wylie et al., 2016). The project uses income gained through both PES and REDD+ frameworks to fund small-scale community-based mangrove restoration. Mikoko Pamoja covers 117 ha of mangroves and in 2019 it sold almost 2000 credits with 65% of the revenue going to support local community projects (Macreadie et al., 2022). The emphasis on community involvement within the project has been highlighted as the core reason for its success (Huff and Tonui, 2017; Kairo et al., 2021). Other benefits seen as a direct result of the mangrove restoration are increased fish populations (Debrot et al., 2022), enhanced biodiversity and more resilient shorelines (Huff and Tonui, 2017). In response to the success of Mikoko Pamoja, replicas of the project have started to appear across the Kenyan coast, with the Vanga Blue Forest project launching in 2019 in south-eastern Kenya and a future blue carbon project set to launch in Lamu County imminently.

The Mikoko Pamoja project highlights how mangroves can support ecologically and socially sustainable management of the landscape. If implemented successfully, other mangrove blue carbon projects such as the MICP could bring direct and indirect benefits to local communities. Potential direct benefits include roles safeguarding the mangroves and protection from shoreline erosion, while possible indirect benefits include increased fish populations, and alternative sources of income, such as making and selling honey from the bees residing within the mangroves and increased biodiversity (County Government of Lamu, 2018; Huff and Tonui, 2017).

Working at a community level is consistently seen as critical within carbon projects because local communities have considerable knowledge and dependence on their local ecosystems (Hespen et al., 2023; Leal and Spalding, 2022). This is particularly true of Kenyan mangroves, with research estimating that the communities living adjacent to mangroves derive 80% of their wood requirements from the forests (County Government of Lamu, 2018; Riungu et al., 2022). Those who rely on mangrove logging are estimated to earn a net monthly income of $118 (Riungu et al., 2022) therefore either compensation or the creation of alternative livelihoods must be considered to stop illegal harvesting. This challenge is compounded by harvest data compiled by the Kenya Forestry Service suggesting the Lamu forests are underexploited, which is in direct contrast to academic studies of the area which indicate a forest at risk of anthropogenic degradation (Ahmed et al., 2023; Kairo et al., 2021; Riungu et al., 2022). In this context, whilst it would be beneficial to implement sustainable mangrove management programmes across the Kenyan coast, it may be hard to secure the support of the local communities who derive their livelihoods through mangrove logging. There also remains a risk that the Kenya Forestry Service continues to issue licences for mangrove logging based on their own datasets, leading to further degradation of the mangroves.

The prominence of mangrove cover across Kenya can be slightly different depending on the area, therefore carbon sequestration calculations and the formation of any NbS for mangroves are localised and site specific. As such, there is a lack of existing literature and research pertaining to the specific mangroves found within the Manda Island Conservancy Project and the viability of those mangroves to form a blue carbon project.

3. Aims, Objectives and Research Questions

This dissertation investigates the potential of the mangroves found within the Manda Island Conservancy Project to form the basis of a blue carbon project and explores how the mangroves can support ecologically and socially sustainable management of the landscape. Mangroves provide a natural method of removing carbon, whilst providing multiple co-benefits to the land and local communities. This dissertation will therefore analyse the carbon stock potential of the mangroves and how mangrove cover has changed over time, using the findings to determine whether the mangroves could become a NbS on the voluntary carbon markets. The dissertation will also discuss limitations and identify areas for future research.

To deliver on these outcomes the following research questions will be answered:

Q1: How much carbon is stored in the MICP mangroves?

Q2: What has happened to mangroves in the MICP and the adjacent area over time?

Q3: Is it commercially viable for carbon finance from the mangroves in the MICP to contribute to sustainable conservation?

Q4: How could protected mangroves in the MICP support socially and ecologically sustainable management of the landscape?

Q5: What observations should be prioritised for future work in this area?

4. Methodology

4.1. Study site overview – the Manda Island Conservancy Project

The study site is the Manda Island Conservancy Project, located on the north-eastern side of Manda Island, in the Lamu Archipelago off the northeast coast of Kenya with co-ordinates: -2.245, 40.979. Manda Island is one of the five major islands of the Lamu Archipelago. Lamu lies directly within the East African Coastal Forest Ecosystem which stretches across parts of Somalia, Kenya, Tanzania and Mozambique (Burgess et al., 1998). These coastal forests are recognised as biodiversity hotspots and are home to many endemic species living within a unique mosaic of marine and terrestrial coastal forest systems (County Government of Lamu, 2018; Kairo et al., 2021; Kirui et al., 2013; Owuor et al., 2019).

The characteristic features of Lamu include coastal lagoons, multiple small islands, hot temperatures and high humidity, all of which support the growth of healthy mangroves (County Government of Lamu, 2018). According to the Kenyan government between 62% and 75% of Kenya's mangroves are found within Lamu, giving the area its unique identity (County Government of Lamu, 2018; GoK, 2017). In 2013, The Kenya Forestry Service documented that the mangrove ecosystems in Manda Island underwent drastic reductions between 1997-98 due to both felling for fuelwood and the El Niño rains, which severely damaged some of the natural ecosystems (Kirui et al., 2013).

The Manda Island Conservancy Project, which was initiated in January 2022, currently covers approximately 1,000 ha of undeveloped land in the north-eastern corner of Manda Island, including the adjacent island of Manda Toto (Figure 4.1). The MICP is in the process of creating a wildlife conservancy to protect and restore the unique marine and terrestrial forest ecosystems and recover wildlife across the area. The project will also invest in training and education facilities to increase conservation related capacity, forging partnerships with scientists, educators, Non-Governmental Organisations (NGOs) and other conservation entities across the Kenyan coast.

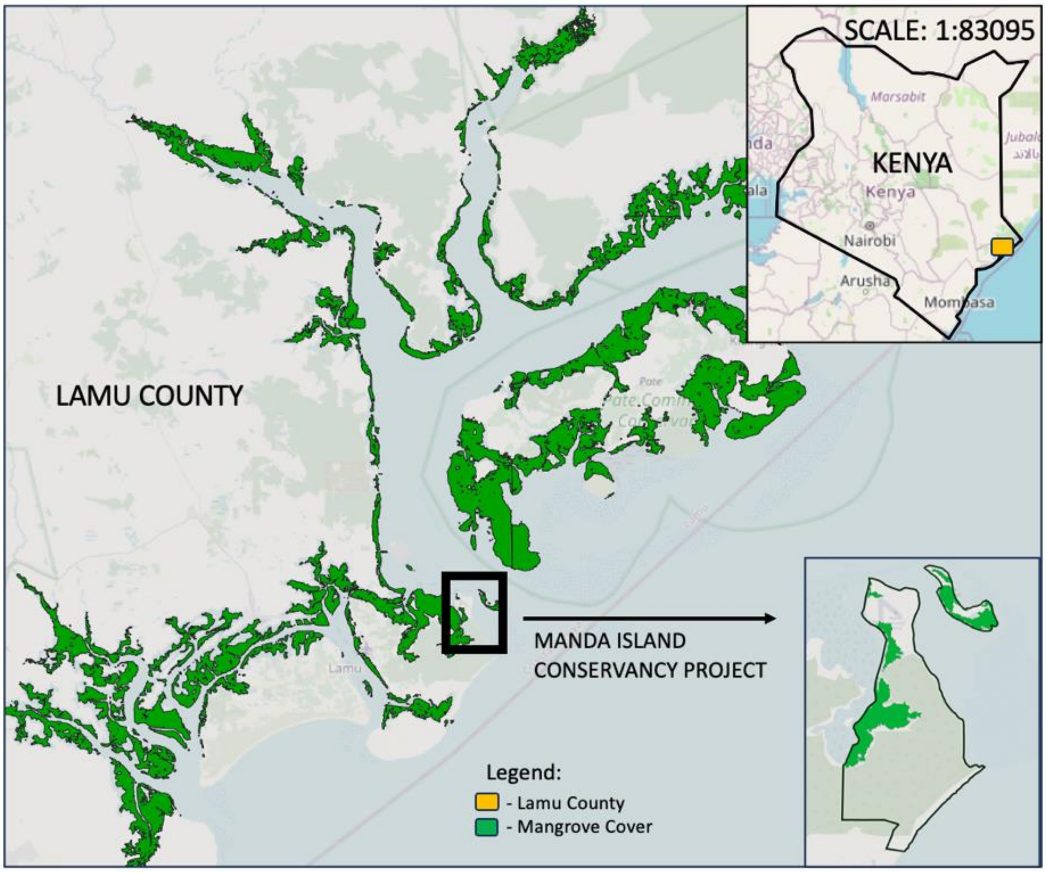

Figure 4.1. Visualisation of the Manda Island Conservancy Project in Lamu County. *Figure also highlights the 2020 mangrove coverage shown across Lamu County and the Manda Island Conservancy Project with the mangrove cover shown in green.*

4.2. Research design

This dissertation uses quantitative methods to calculate the mangrove cover across the Manda Island Conservancy Project and Lamu County. Calculations were also included for Lamu County to understand the broader trends within the regional landscape. To maximise the accuracy of the mangrove cover within the MICP, remotely sensed data from the Global Mangrove Alliance is used. Remote sensing refers to data which has been acquired from a distance, for example through the use of satellite imagery (Cracknell, 2007). The data was downloaded and imported into the free open-source software QGIS, which is often used when estimating mangrove forest cover and analysing change (Aljenaid et al., 2022; Kairo et al.,

2021) and is a useful software tool when on the ground measurements are unavailable, as is the case with this research.

The following analytical techniques are used to address the research questions set out in part three. Research question one and two are addressed by applying QGIS geoprocessing tools to the dataset to provide an estimated calculation of mangrove cover. Further analysis to understand the mangrove cover change over time is conducted in RStudio, where time-series data is analysed. A critical analysis of literature around carbon markets, including the status of the market and the cost of registering a new project is used to answer research question three. Question four is addressed by using systems thinking to model a mangrove ecosystem and its interconnections to highlight the areas which would be affected by mangrove degradation, therefore making a case for sustainable management. Question five is answered using the results provided from the previous questions.

4.3. Datasets

Remote sensing represents a feasible way of obtaining information on land cover in a temporally and spatially consistent way (Bullock et al., 2021; Hamza et al., 2022) and for this dissertation project three different datasets were considered. The first was The Global Tidal Wetland Change (1999 - 2019) produced by Murray et al (2021), the second was the Global Mangrove Forest Distribution (2000) produced by Giri et al (2000) and the third was The Global Mangrove Watch 3.0 (GMW 3.0) dataset produced by Bunting et al (2022). The Global Tidal Wetland Change dataset was considered due to its comprehensiveness measuring cover change over the years. However it does not provide specific mangrove coverage classifications, only changes for tidal wetlands as a whole, a limitation noted by the authors (Bunting et al., 2022b), and consequently was not suitable to assess MICP mangrove coverage. Initial analysis revealed the Global Mangrove Forest Distribution dataset recorded no mangroves within the Manda Island area, which is inaccurate.

The Global Mangrove Watch 3.0 dataset builds on the previous Global Mangrove Watch 2.5 dataset. The Global Mangrove Watch dataset has developed a baseline that has been refined over four generations, evolving to support conventions such as the Paris Agreement set out by the United Nations Framework Convention on Climate Change, is currently used for reporting on the UN SDGs and has been used to create extensive maps for the Global Mangrove Alliance (Bunting et al., 2022a; Spalding and Leal, 2021). The GWM 3.0 dataset uses L-band Synthetic Aperture Radar (SAR) global mosaic datasets from the Japan Aerospace Exploration Agency (JAXA) for 11 different years over a 24-year period from 1996 to 2020 to create an extensive and long-term time series of global mangrove extent and change. It has a spatial resolution of 30m, with an accuracy of 87.4%, determined by using accuracy points across 20 globally distributed sites (Hamza et al., 2020). The GMW 3.0 dataset is considered the most comprehensive record of mangrove change across the globe to date and is expected to continue to be used to support international agreements and conventions (Bunting et al., 2022b). Due to the limitations of the first two datasets and the improved characteristics of the GMW 3.0, it was used throughout this study to determine both the baseline of mangroves present in the MICP and to calculate changes in mangroves across the study site and the Lamu region over time.

4.4. Calculating carbon stock within the MICP mangroves

Following the selection of the GMW 3.0 dataset, data for each of the available 11 years (1996, 2007, 2008, 2009, 2010, 2015, 2016, 2017, 2018, 2019 and 2020) was downloaded as vector layers and uploaded into QGIS. As QGIS is a freely available and transparent tool, it is often used when analysing both forest cover and cover change (Aljenaid et al., 2022; Kairo et al., 2021). Polygons designating the boundaries of the MICP were supplied by the MICP project personnel and subsequently uploaded into QGIS. Mangroves around the Manda Toto island that appeared outside of the boundary originally provided were included in the calculations at the request of the MICP personnel. The data for each year was then isolated and clipped within the MICP boundaries. The total number of hectares of mangroves per year was rounded up or down to the nearest hectare.

The final year of data available was 2020, therefore this was the data which was used to estimate the current carbon stock. Once the 2020 data was isolated within the MICP boundaries, the field calculator tool within the attribute table for the vector layer was used to calculate the area of the mangroves within the MICP. Above ground biomass of the mangroves was estimated based on an area to biomass relationship published by Kairo et al (2021). An assumption of the total ecosystem carbon stock in the MICP mangroves was made based on the available data and by using the carbon stock calculations of Lamu mangroves also published by Kairo et al (2021), whose calculations incorporated above ground biomass carbon, below ground biomass carbon, total biomass carbon and soil organic carbon of mangroves in the area.

To estimate above ground biomass, the following calculation was used, where Y represents the above ground biomass estimation given by Kairo et al (2021) per hectare and X represents the total area of mangroves in the MICP in ha:

$$X * Y = \textit{Above Ground Biomass}$$

To estimate total ecosystem carbon stock, the following calculation was used, where B represents the total ecosystem carbon stock estimation given by Kairo et al (2021) per hectare and A represents the total area of mangroves in the MICP in ha:

$$A * B = \textit{Total Ecosystem Carbon}$$

4.5. Mapping and analysing mangrove cover change across Lamu County and the MICP

To understand the total mangrove cover of the MICP and Lamu County, the question one workflow in QGIS was repeated to calculate the mangrove area. For Lamu County, this required the creation of a separate polygon encompassing the boundaries of the county.

For both Lamu County and the MICP, changes across the 24-year period of observation were quantified using the post-classification overlay detection method, which involves overlaying maps from each of the 11 different years and using geoprocessing tools to identify areas of loss, gain, and no change. For details of the methodology see table S1 in Supplementary Information.

4.6. Data analysis and visualisation

Post processing of the data was done in RStudio. R was chosen as the coding language because it is open-source, and RStudio is freely available to use. The data was taken from QGIS and uploaded into RStudio. The code for processing and analysing this data along with additional explanatory notes is available in this repository:

https://github.com/TESS-Laboratory/Shaw_dissertation_Manda_Island_Mangroves.

5. Results

5.1. Carbon stock calculation of the MICP mangroves

The total mangrove cover within the MICP is estimated to be 169 hectares (Figure 5.1), representing 16.9% of the total area of MICP. To calculate the carbon stock, assumptions were made based on the findings from the Kairo et al (2021) research, which calculated the total ecosystem carbon stock of the mangroves across Lamu County. Kairo et al (2021) found that within the area around the MICP the mangroves had an average above ground biomass carbon of 129.43 Mg C ha^{-1} and a total ecosystem carbon stock of 525.36 Mg C ha^{-1}.

Using these figures as baselines, the calculations were undertaken to estimate both the above ground biomass carbon stock and the total ecosystem carbon stock held within the MICP mangroves. The results showed the MICP mangroves have an estimated above ground biomass carbon stock of 21,873.67 Mg C and a total ecosystem carbon stock of 88,785.84 Mg C.

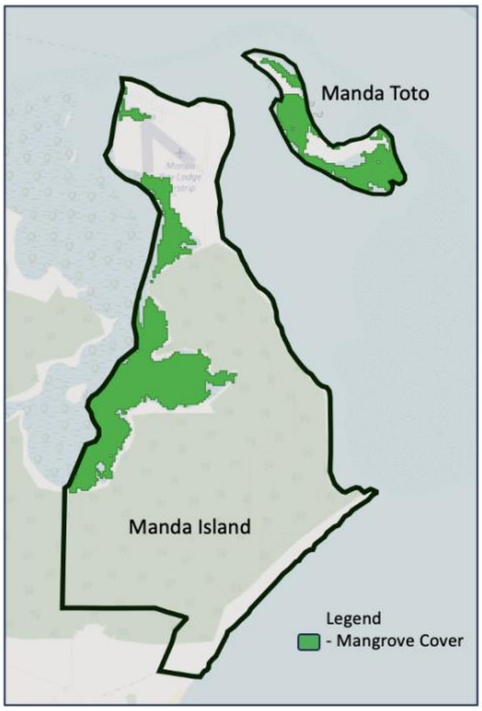

Figure 5.1. Visualisation of the MICP highlighting the 2020 mangrove cover. *Mangroves, depicted here in green, were calculated to cover a total area of 169 ha within the boundaries of the MICP.*

5.2. Mangrove cover change over time in Lamu County and the MICP

The analysis of the remotely sensed data from the GWM 3.0, shows that mangrove coverage in both the MICP and Lamu County has not remained static (Figure 5.2). Lamu County experienced a decrease of 0.3% whereas the MICP experienced an increase of 3% in mangrove cover. Table S2 in Supplementary Information shows a breakdown of mangrove coverage by year for each site.

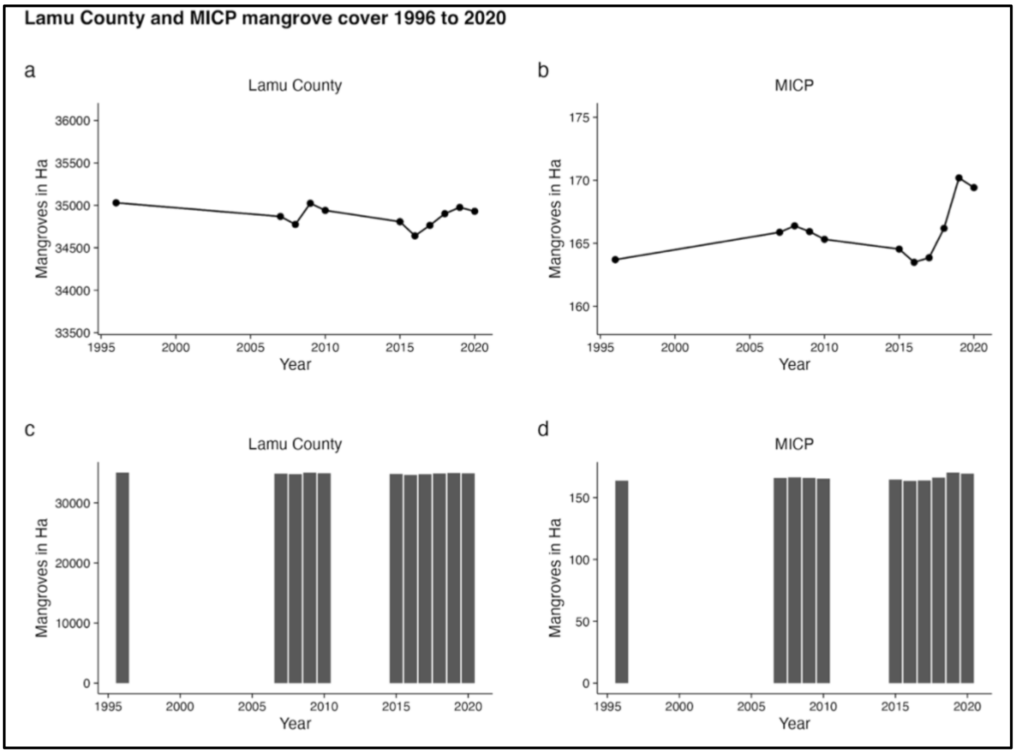

Figure 5.2. Visuals showing a time series of mangrove cover change across Lamu County and the MICP. *Graphs a and b have a slightly truncated Y axis, so the reader is able to observe the trends over time, whereas graphs c and d have an untruncated Y axis scale to contextualise the small relative change.*

The results show between 1996 and 2020 mangrove coverage levels in the MCIP increased by 5 ha from 164 ha to 169 ha, which equates to an increase of 3% of the total area over the course of the 24 years of observation (Figure 5.3). Between the years of 1996 and 2008 the mangroves increased from 164 ha to 166 ha, the equivalent of 0.2 ha of growth per year over the 12-year period, however between 2009 and 2017 the mangroves decreased by 1% from 166 ha to 164 ha. From 2017 through to 2020 the mangroves recovered and increased year on year from 164 to 169 ha, equating a gain of 5 ha.

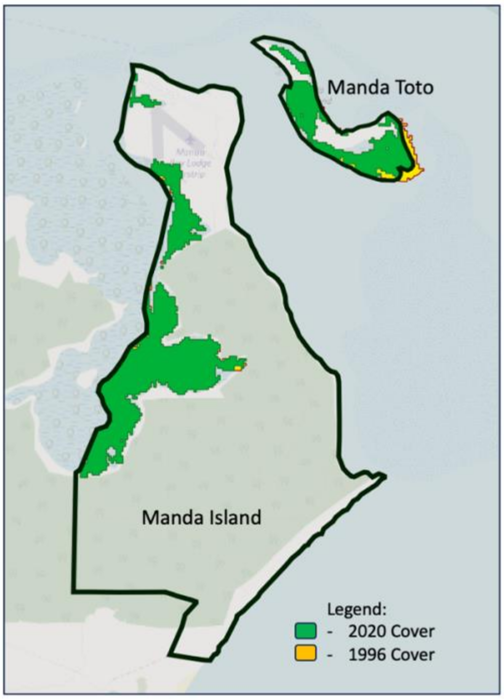

Figure 5.3. Visualisation highlighting the difference between mangrove cover in 1996 and 2020 across the MICP. *The MICP cover was calculated to be 169 ha with a gain of 5 ha, the areas shown in this diagram in yellow areas where in 1996 there was mangrove cover, these areas have offset with gains across the 24-year period of observation.*

The total number of mangroves in Lamu County in 2020 is 34,930 ha (Figure 5.4). In contrast to the mangroves within the MICP, the mangroves in Lamu County declined between 1996 and 2020 from 35,030 ha to 34,930 ha with an overall loss of 100 ha (Figure 5.5), equating to a relative loss of 0.3% of the total area over the course of the 24 years of observation (Figure 5.2). However, throughout this period the mangrove cover in the county did not remain static with the county experiencing frequent loss and gains. Between the years of 1996 and 2008 the mangrove cover in Lamu decreased from 35030 to 34775 by 255 ha, a loss of 0.7%. Cover increased by 249 ha between 2008 and 2009, offsetting almost all the previous loss, however from 2009 to 2017, cover declined again from 35,024 to 34,764 by 260 ha. From 2018 to 2020 mangrove cover in Lamu remained relatively static with an overall loss of 28 ha. Figure 5.6 shows a close-up sample image of the mangrove loss and cover in Lamu County.

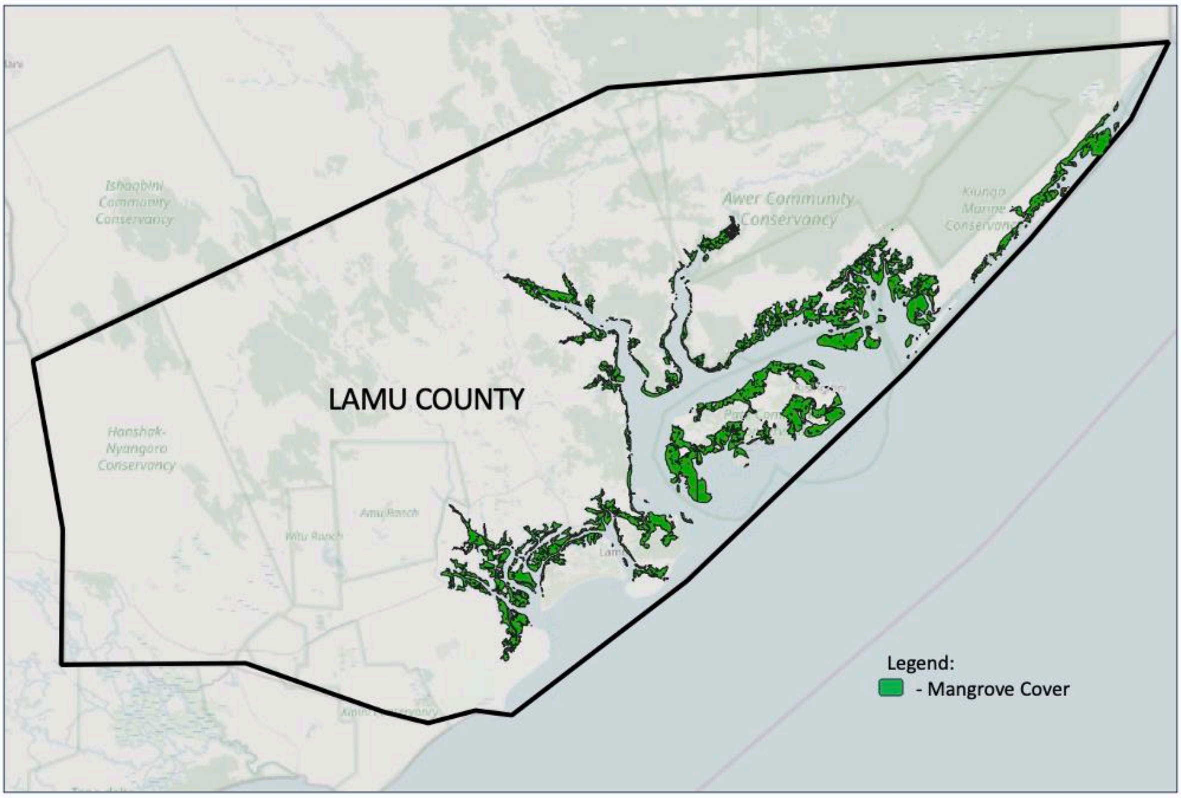

Figure 5.4. Visualisation of the 2020 mangrove cover across Lamu County. *Mangrove cover was calculated to be 34,930 ha, shown in green.*

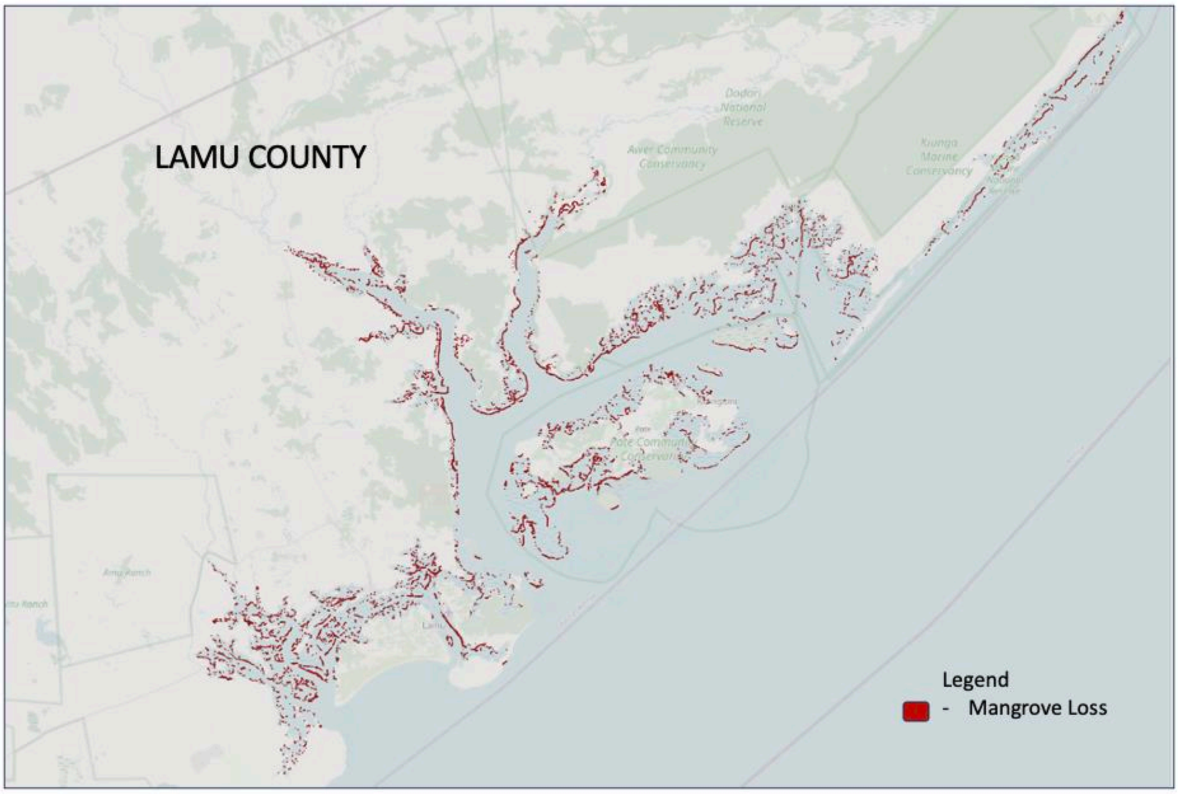

Figure 5.5. Visualisation of the total loss of mangroves across Lamu County between 1996 and 2020. *Mangrove loss was calculated to be 100 ha, shown in red.*

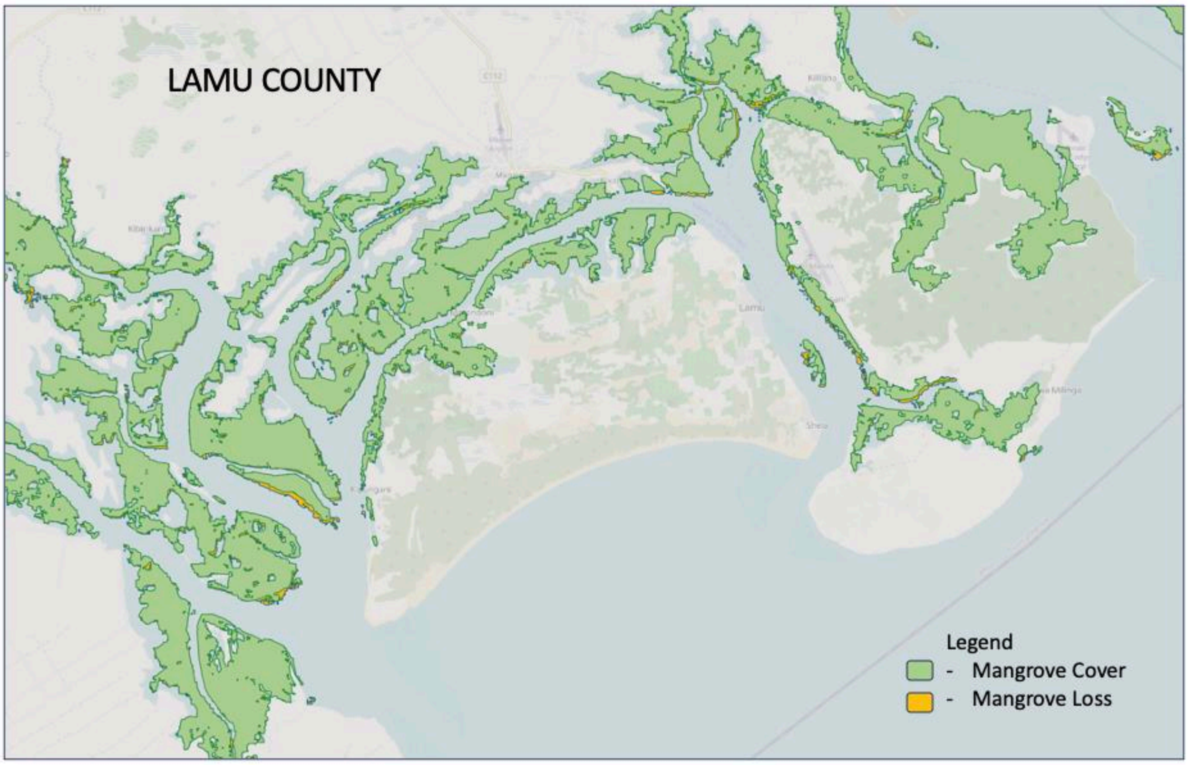

Figure 5.6. Visualisation highlighting both the coverage and loss of mangroves across Lamu County. *A close-up image of Lamu County taken to highlight areas of loss, shown in yellow.*

Whilst Lamu County experienced an overall loss in mangroves, the MICP experienced a gain in mangrove cover across the 24-year period between 1996 and 2020. The scatter plots shown in Figure 5.2 highlight the detail of the change. A graph highlighting the percentage change comparison between each observation year can be found in Supplementary Information (S3).

5.3. How much income could the MICP mangroves make on the current carbon market

The MICP mangrove carbon stock has a substantial value. According to the World Bank, in the current market, each carbon credit represents one tonne of carbon which is either reduced or removed from the atmosphere, and the current 2022 average price for a carbon credit is $6.4 per tonne of carbon, although this can increase to $25 depending on the project (Allied Offsets, 2022; World Bank, 2023). Taking the total ecosystem carbon stock estimation of 88,785.84 Mg C in question one, this would amount to an estimated total value of $568,299 for the MICP mangroves. The total ecosystem carbon stock was used rather than the above ground biomass calculation to give an estimation of the total value for the entire carbon stock held within the mangroves.

Using publicly available information from the Mikoko Pamoja project within the same national jurisdiction an alternative calculation can be undertaken to estimate an average annual income for the MICP mangrove carbon stock. The Mikoko Pamoja mangroves cover 117 ha of land, sequester over 2,000 tonnes of carbon and gain roughly $12,000 per year through the sale of carbon credits accredited by Plan Vivo (Plan Vivo, 2020; UNDP, 2020). This equates to 17 tonnes of carbon per ha which are traded at the price of $6 per tonne. Taking the MICP area of 169 ha and assuming a similar sequestration rate, this would equate to 2,873 tonnes of carbon being sequestered each year. At the same sale price of $6 per tonne, this would equate to the MICP gaining an annual income of $17,238.

6. Discussion

6.1. Carbon stock assessment of the MICP mangroves

The above ground biomass carbon stock of the MICP mangroves is calculated as 21,873.67 Mg C with a total ecosystem carbon stock calculated at 88,785.84 Mg C, while the total ecosystem carbon stock per hectare is given as 525.36 Mg C ha^{-1}, which is within the global range of total ecosystem carbon stock for mangroves (Kauffman et al., 2020) and compares favourably to other localised projects in Africa (Figure 6.1). Notably it compares well to studies in Madagascar, estimated at 454.92 Mg C ha^{-1} (Benson et al., 2017), Tanzania estimated at 414.6 Mg C ha^{-1} (Alavaisha and Mangora, 2016) and South Africa, which estimated total ecosystem carbon stock of 234.9 Mg C ha^{-1} (Johnson et al., 2020). However it is lower than studies in Gabon estimated at 644 Mg C ha^{-1} (Trettin et al., 2021). A table detailing the methods used withing the comparative literature in Figure 6.1 is available in Supplementary Information (S4).

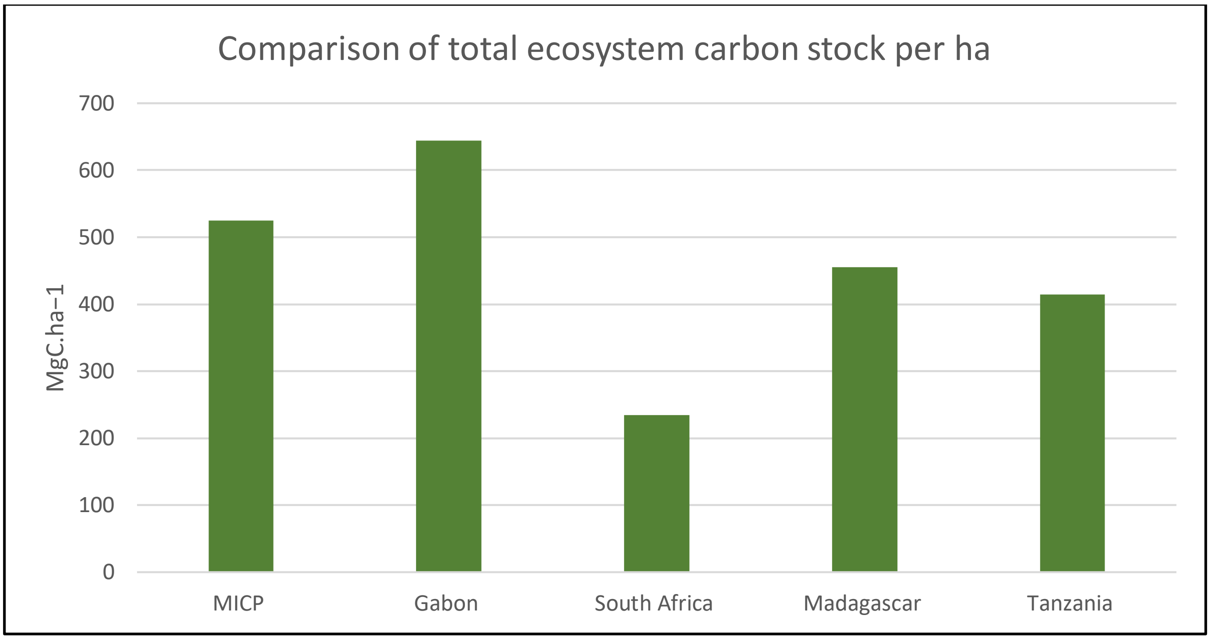

Figure 6.1. Bar chart highlighting how the total ecosystem carbon stock of the MICP compares to other mangrove projects across Africa. *Each bar represents the total ecosystem carbon stock per hectare across the different sites found in Africa.*

Mangrove carbon stock is determined by several factors including a wide variation of environmental drivers such as localised weather conditions, mangrove species and density that influence mangrove productivity when sequestering carbon (Kauffman et al., 2020; Trettin et al., 2021). Mangroves can contain 70% of their carbon within their soil (Macreadie et al., 2022), highlighting the important role for field work to determine soil organic carbon content in the assessment of any mangrove carbon project. The calculations presented here incorporate informed assumptions of carbon stock held within the soil from the Kairo et al (2021) research.

However, it was not feasible to conduct field work for this dissertation on the specific MICP mangroves, therefore, the total ecosystem carbon calculation presented here should subsequently be validated with fieldwork.

Additionally, the most recent available GMW 3.0 dataset is 2020. Mangroves have been documented to have a fast growth rate (Spalding and Leal, 2021) and therefore it is possible that since 2020 there has been new mangrove growth or loss across MICP, which would have an impact on the above calculations.

6.2. Analysis of mangrove cover change in Lamu County and the MICP

There are noteworthy differences between the Lamu County mangrove coverage time series analysis conducted for this dissertation and other recent research. The total MICP mangrove cover increased by 5 ha, whereas the mangroves in Lamu County saw a decrease of 100 ha across the 24-year period of observation. The Lamu County figure presented in this dissertation is substantially lower than the average loss of 60 ha per year across the Lamu region identified by Kairo et al (2021), over a similar period of observation between 1990 and 2019 and equating to a total loss of 1740 ha of mangroves. These differences could be due to known classification errors and limitations of the GMW 3.0 dataset and the fact the calculations provided by Kairo et al (2021) were based on fieldwork, which verified their remotely sensed data. This disparity suggests fieldwork in the MICP would be valuable to validate the accuracy of the recorded mangrove coverage. Additionally, a decade of data (between 1996 and 2007) is not available within the GMW 3.0 dataset and these years coincide with the years (1997-1998) highlighted by the Kenya Forestry Service where it was documented that a vast number of mangroves were lost due to El Niño storms. Due to the unavailable data, it is also noted that, should the 1996 value be inaccurate, it would have a disproportionate effect on the results.

Despite mangrove protection plans actioned by conservationists and local government bodies, it is likely mangrove coverage in Lamu County will continue to decline due to the combination of climate drivers, mangrove harvesting and the development of Lamu Port. It is well documented that mangrove loss occurs due to both local anthropogenic pressures such as urbanisation and felling and global drivers such as climate change (Goldberg et al., 2020; Hamza et al., 2022; Murray et al., 2022). Lamu County also has a long history of commercial harvesting and marketing of mangrove poles, with estimates suggesting this practice currently supports over 30,000 local families and at the start of the dataset in 1996 the county was exporting some 275,488 poles a year (Riungu et al., 2022). Harvesting mangroves legally requires licensing from the Kenya Forestry Service, however illegal harvesting continues to be an issue as there is an inbuilt local belief that mangroves are a never ending source of wood (County Government of Lamu, 2018). In 2019, the County Government of Lamu passed a logging ban to stem the flow of illegal harvesting, however, following lobbying from local communities, this was overturned by the high court in Nairobi (Praxides, 2023) and logging continues to be an issue. In addition to mangrove harvesting, research suggests 80% of the labour force in Lamu County derive their livelihood from services influenced by the mangroves such as fishing, subsistence farming and eco-tourism (Riungu et al., 2022). It is also likely the decline of mangroves highlighted in Lamu County over the period of observation has been influenced by the construction of the Lamu Port which started in 2012 and impinges on Manda Island. The port, which is set to be completed in 2030, has already cleared large areas of mangroves and, according to analysis by the World Wide Fund for Nature (WWF) 150,000 ha of mangroves will be directly removed, with a further 9,400 ha indirectly affected, representing 38% of the current mangroves across the area (WWF, 2016).

In contrast to Lamu County, the MICP mangrove numbers increased over the 24-year observation period. This is likely to be due to several factors including that some areas within the MICP are inaccessible by local communities. For example, Manda Toto is only accessible via boat, which would pose a challenge to individuals illegally harvesting the mangroves. Furthermore, the Manda Bay Hotel, which encompasses the northern part of MICP, has full time security and offers eco-tourism bird-watching tours in and around the mangrove forests on a daily basis (Manda Bay, n.d.). Together, these factors make it harder for illegal harvesting and removal of mangroves to take place without detection. Understanding these local environmental changes is vital when establishing potential blue carbon projects as the protection and longevity of projects is key (Macreadie et al., 2022). Due to this protection and the challenges with accessibility, the MICP is likely to have a higher rate of success as a blue carbon project than other areas of Lamu County.

Figure 5.2 shows that mangrove cover increased in both the MICP and Lamu post 2016, which could be due to several influencing national and international factors. Firstly, prior to 2016, the Kenyan government had no regulation or overarching plan for mangroves, however its first national mangrove management plan was launched in 2017, which mapped out mangrove restoration plans and offered key recommendations for each of the counties to implement over the next decade (GoK, 2017). Meanwhile, on the international stage, the Paris Agreement entered into force in November 2016, cementing the importance of conservation and enhancement of carbon sinks for all parties, including Kenya (UNFCCC, 2018). Despite the national commitments and international pledges, it is not realistic to assume all the lost mangroves in Lamu County and the surrounding areas can be recovered. Mangrove logging is part of Kenyan coastal livelihoods and subsequent anthropogenic loss can be attributed to urban development, including the creation of the Lamu Port, therefore it is improbable these can be restored to their natural state.

6.3. The viability for carbon finance from the mangroves within the MICP to contribute to sustainable conservation.

The MICP is comparable to the Kenyan Mikoko Pamoja project in scale. Compared with other successful blue carbon projects globally such as the India Sundarbans Mangrove Restoration Project (6,000 ha) and the Blue Forests Madagascar project (26,000 ha) (Wylie et al., 2016), the MICP project would be classed as small, however, the MICP mangroves cover a larger area than the Mikoko Pamoja project. Publicly available information highlights a similar mangrove density and species in Mikoko Pamoja to those found in Lamu by Kairo et al (2021). Therefore, the MICP may be able to replicate the Mikoko Pamoja project, using the base value as a starting point and increasing mangrove coverage year on year. However, building a viable carbon project to finance sustainable conservation relies on several factors which necessitate further assessment.

A full baseline assessment will need to be done across the mangroves found within the MICP. This in part is due to the fact that the composition and stature of mangroves varies according to their climate, topography and salinity (FAO, 2023). As carbon offsets are often intangible, additionality tests are used to recognise their value and to distinguish between projects which would have reduced carbon anyway and projects that achieve an additional carbon reduction (Liu and Cui, 2017; Michaelowa et al., 2021). The projects considered additional are eligible for carbon offsets, however additionality tests require baselines to be set, which as previously outlined can be miscalculated, manipulated, underestimated or overestimated (Liu and Cui, 2017). As the science around baseline setting is still nascent, this creates a challenge for the MICP which needs to be confident the metrics used will not be unexpectedly updated, requiring a new baseline to be set.

There is also no guarantee the price calculated within the results section of this paper would be the same once the project is registered. Currently the VCM lacks any form of standardised price regulation, meaning values tend to continually fluctuate across the different credits and there is no maximum price cap for carbon offsets because the VCM is governed by the market and what customers are willing to pay (Allied Offsets, 2022). This means, should the MICP decide to become a blue carbon project, the choice of verifier will be fundamental to success. Registering a carbon project incurs standard initialisation fees, however the costs differ depending on the verification organisation. Table 6.1 provides an overview of the pricing structures offered by some of the largest verification organisations, including Plan Vivo who work with Mikoko Pamoja and certify any credits they create and trade on the carbon markets. Carbon verification cost, relevant regulation and additional funding sources should be considered before a project is started. The costs of starting and maintaining a carbon project vary depending on the verification organisation, the size of the project, the amount of carbon which can be sequestered and the longevity of the project.

Carbon Trading Verification Organisations	Service Fee (USD)				
	Account Setup	**Annual Fee**	**Project submission and registration Fee**	**Project Review Fee**	**Verification Issuance Fee**
Verra	*$500*	*$2500*	*(Estimated annual volume of emission reductions2) x ($0.10); capped at $10,000.*	*$2000-$13,000*	*$0.14 - $0.5 per credit*
The Gold Standard	*$1000*	*$1000*	*Variable – dependent on the size of the project*	*Variable - charged by a third party*	*$0.15 - $0.5 per credit (minus project review fee)*
Climate Action Reserve	*$500*	*$500*	*$500-$700*	*$1,350 + dependent on project size*	*$0.3 per credit*
Global Carbon Council	*Free*	*$1000*	*$3000*	*$2000*	*$0.15 - $0.3 per credit*
Plan Vivo	*$1000*	*$2000*	*$1000-$2000*	*$1500 - $3000*	*$0.5 per credit*

Table 6.1. Table highlighting the pricing structures offered by different verification companies. *Upfront costs required with registering a new carbon project can be estimated using this comparison table.*

Considering the upfront costs associated with carbon projects, if the MICP decide to pursue a project it is recommended that the MICP undertake a full economic assessment of the different verification options and financial forecasting of associated fieldwork costs to validate the viability of the project. Additionally, noteworthy amendments to the Kenyan Climate Change Bill are currently under review including a requirement that future carbon projects give 25% of the aggregate earnings to local communities (GoK, 2023). Whilst this has not been passed, it should be included within any future financial forecasting. Lastly, as part of the project economic assessment, further research should be conducted into areas where the MICP may be able to acquire additional funding. For example, Mikoko Pamoja lists several organisations as additional funders including Kenya Marine Fisheries Institute, Earthwatch Institute, Edinburgh Napier University and Plan Vivo, who also draw on their expertise to create systems of governance (Plan Vivo, 2020; Wylie et al., 2016). It therefore stands to reason that the MICP may be able to secure funding from external agencies to aid in the implementation of the project and navigate any policy and regulatory changes on behalf of the MICP.

Internationally, there are focused efforts to encourage wider geographical participation in carbon credit markets and higher quality credits that could be advantageous for the MICP. One such project is the Africa Carbon Markets Initiative which aims to have 300 million carbon credits from African projects retired annually by 2030. The Africa Carbon Markets Initiative, which was inaugurated at COP27, has seen many African nations, including Kenya, pledge to grow voluntary carbon markets across the continent. The increased appetite for carbon projects may place the MICP in a strong position because, in addition to their carbon stock, mangroves offer biodiversity and ecosystem services, therefore have the potential to fetch a higher price (World Bank, 2023). This ties in with a wider carbon market trend as the market continues to diversify and increase in sophistication with a worldwide emphasis on evaluating the quality of carbon credits (Hespen et al., 2023).

The viability of the MICP forming a blue carbon project to finance sustainable conservation also relies on the national Kenyan jurisdiction and the frameworks and regulations around carbon trading and the voluntary carbon markets that are currently under review. These upcoming changes in regulation are part of a worldwide trend, where increasingly more countries are looking to set up their own domestic crediting mechanisms (World Bank, 2023). In many ways, the Kenyan update to carbon credit regulation is overdue and could be a positive move for the government, helping to streamline international frameworks when they are applied locally. Recent research found frameworks around popular carbon crediting systems such as REDD+ degenerated into negative policies within the Kenyan political systems due to bureaucracy, corruption and sectoral competition for carbon finance across forestry, lands and agriculture (Atela et al., 2016). Implementing new frameworks and policies in this sector could provide an opportunity for local policymakers to understand where current policies are failing and correct them accordingly. However, the full scope of the review is not known and the amendment to the national Climate Change Bill has not been passed through parliament yet, so no concrete recommendations can be made in this dissertation based on the new regulation.

In addition to the new regulation, the Kenya Forest Conservation and Management Act presents challenges for the MICP because it classifies mangrove forests as part of public Kenyan forests, suggesting the primary role of management lies with the Kenya Forestry Service (Ahmed et al., 2023). This raises important questions as to who would be responsible for creating, managing, and benefiting from the project, and could result in potential legal disputes. There are also concerns around how corruption may be entwined within localised carbon markets. Corruption is endemic within Kenya (Hope, 2014), and this reliance on corruption can enhance weak regulatory frameworks which in turn can facilitate 'green grabbing' which refers to the appropriation of resources and land for environmental enrichment (Vidal, 2008). This is a key concern for both new and existing carbon projects within the country.

Using the success of the Mikoko Pamoja project and the area and mangrove sequestration rates as a baseline for success, the MICP would be able to register and operate a commercially viable project that would generate carbon finance from the mangroves to contribute to sustainable conservation. Long-term permanence of the project, however, will depend on the outcome of the full economic assessment, whether the MICP is able to gain additional funding and how new legislation and accompanying regulation for carbon markets in Kenya are realised at a localised level for the MICP.

6.4. Using the mangroves to support socially and ecologically sustainable management of the MICP landscape

Sustainable management in forestry is an evolving and dynamic concept that aims to maintain and enhance the environmental, economic and social values of forests for the benefit of future and present communities (Ahmed et al., 2023). As mangrove ecosystems are interconnected and interact through a series of feedback loops, any form of management plan should aim to include the system as a whole as well as an understanding of longevity and timeframes (Murray et al., 2022). Adopting a systems thinking approach to sustainable management of the MICP mangroves provides a framework that can be used to understand how the different components of the system interact and what parts of the system should be prioritised. This is of particular importance as accurate calculations of ecosystem services provided by mangroves, which influence local and national policy, must account for the whole system to ensure all services provided by mangroves are recorded (Leal and Spalding, 2022; Murray et al., 2022).

An understanding of how mangrove ecosystems are interconnected and work through a series of feedback loops should form the basis of any mangrove management plan. If the MICP mangrove ecosystem is maintained sustainably, the feedback loops within the ecosystem work to keep the system balanced, providing the ecosystem services local communities depend on. Should the mangroves in the MICP degrade or be unsustainably harvested, the opposite will occur, leading to the depletion of ecosystem services. There are two types of feedback loops within a system: amplifying and balancing. Amplifying feedback loops self-enhance leading to exponential growth in a system, eventually leading to the collapse of a system if left unchecked, whereas balancing feedback loops are equilibrating and are sources of stability within a system (Meadows, 2008). Figure 6.2 shows a systems dynamics model, highlighting the amplifying feedback loops which could take hold to deplete the ecosystem services should the mangroves degrade and continue to be illegally harvested.

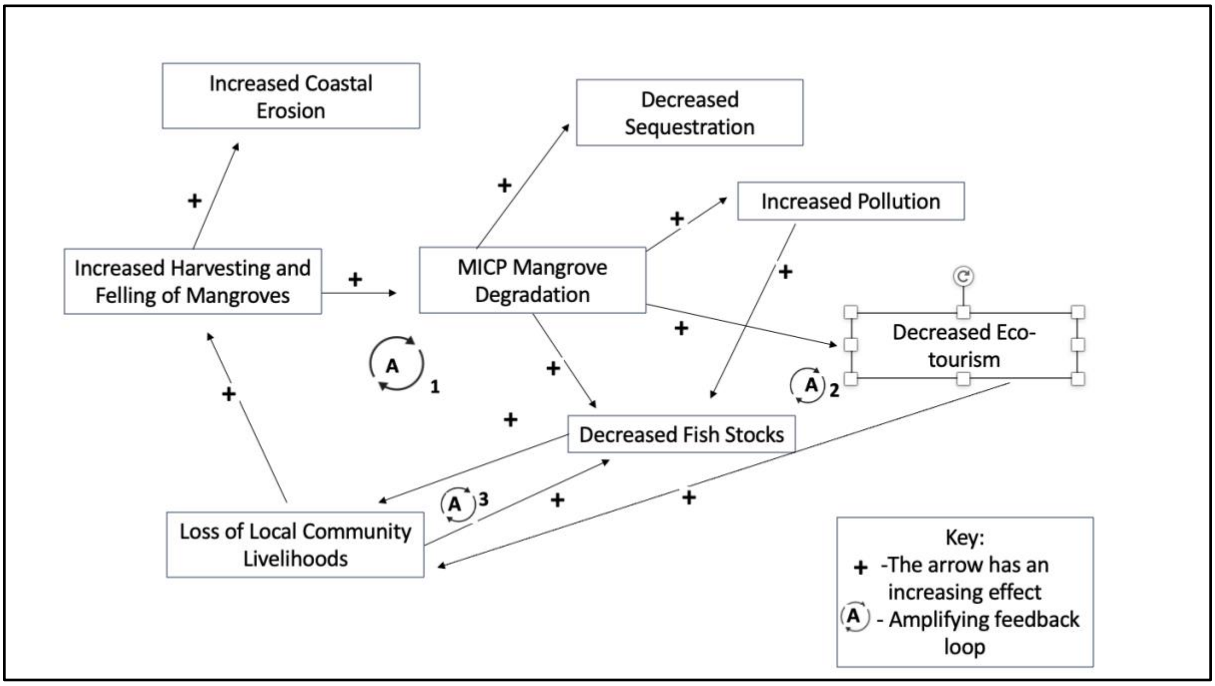

Figure 6.2. Systems dynamics model highlighting the interactions and feedback loops within the MICP mangrove ecosystem. *The diagram shows the amplifying feedback loops which could take hold should the MICP mangroves degrade continuously.*

Figure 6.2 highlights how mangrove degradation within the MICP would lead to a reduction in several of the ecosystem services provided including a decrease in CO_2 sequestration, reduced fish stocks, higher risk of increased coastal erosion, more pollution and decreased ecotourism. The reduction in these ecosystem services would have a substantial impact on local communities, in particular the decreases in fish stocks and ecotourism as they will constitute a loss of livelihood for communities that depend on them. The depletion of fish stocks would lead to a further loss of community livelihoods which could result in two amplifying feedback loops. Firstly, a loss of income from fishing could lead to increased mangrove harvesting as communities look to make alternative livelihoods, resulting in the further degradation of the MICP mangroves (A1). This could be further increased by coastal erosion. Secondly, as the fish stocks deplete, there is a chance those who depend on them for income will continue to fish, driving the fish stocks to further depletion (A3). If left unchecked, this feedback loop could continue until fish stocks are completely depleted, leading to a collapse of that part of the system. In addition to these amplifying feedback loops, should the mangroves degrade continuously without any form of restoration, it could lead to fewer tourists visiting Manda Island, which would have an impact on local job security (A2).

If the MICP mangroves degraded as shown in the Figure 6.2, with the amplifying feedback loops taking hold, the entire ecosystem could reach a tipping point. A tipping point is the point at which a system 'tips' into a new state, which is often irreversible (Lenton, 2020). It is therefore vital these risks are understood and incorporated into future planning for the MICP mangroves. The system dynamics model can be expanded to include the effects of restoration by including the social and biophysical conditions needed for mangroves to naturally colonise suitable habitats and multiply.

The MICP could also use carbon finance from the mangroves to implement the 10-step programme McLeod and Salm (2006) developed during their research into successful and climate resilient mangrove management programmes (Table 6.2). This programme highlights the steps that need to be undertaken to increase the chance of successful and long-term mangrove projects (McLeod and Salm, 2006). Table 6.2 highlights each of the steps and includes a column indicating where these have been adopted by the Mikoko Pamoja project showing which steps are feasible within Kenya and subsequently could be implemented by the MICP.

	Mangrove Management Plan (McLeod and Salm, 2006)	Implemented by Mikoko Pamoja
Step 1	Apply a climate change risk assessment.	Yes
Step 2	Identify and protect mangroves at least risk of climate change.	Yes
Step 3	Manage local community stresses and degradation of mangroves.	Yes
Step 4	Establish boundaries and protected areas.	Yes
Step 5	Restore degraded areas that have demonstrated resistance or resilience to climate change.	Yes
Step 6	Adopt a whole system approach to the mangrove ecosystems.	Yes
Step 7	Establish baseline data and monitor and report any changes.	Yes
Step 8	Implement adaptive strategies to compensate for changes in species ranges and environmental conditions.	Unknown
Step 9	Develop alternative livelihoods for local communities to reduce mangrove reliance and destruction.	Yes
Step 10	Incorporate stakeholder management into the long-term strategy of mangrove management.	Yes

Table 6.2. 10 step management plan as shown by McLeod and Salm (2006). *Table highlights how each step has been adopted by a successful Kenyan blue carbon mangrove project, therefore showing its feasibility for the MICP.*

This framework is not sufficient without modification because it does not consider two important steps that would need to be undertaken by the MICP. Firstly, it does not mention the importance of involving local communities from the start, and secondly, it does not include quantifying the carbon stock of the mangroves. Where carbon projects are concerned it is vital mangrove management actions go beyond the framework in Table 6.2, and are also guided by predictions of future emissions and carbon storage (Adame et al., 2021). Should the MICP create a blue carbon project, understanding annual sequestration potential and avoiding leakage will be central to its success. This requires a comprehensive understanding of the local context around mangrove dependency and illegal and legal mangrove harvesting. It should also be an aim of the MICP to involve local communities in the conservancy project, ensuring they are invested in conservation and able to see the benefits of sustainable land management. Should the amendments to the Climate Change Bill pass through parliament, then it will be a legal requirement to involve local communities with any new carbon project, therefore involving them from conception will be vital to success. It is also important for the MICP to identify where it is suitable to plant new mangrove saplings as one of the factors which contributes to mangrove restoration failure is the overemphasis on replanting in unsuitable habitats (FAO, 2023). Other factors contributing to mangrove restoration failure include a lack of project maintenance, inadequate assessments and baselines, a lack of local community support and poor species matching, highlighting the importance of using already established mangrove species (FAO, 2023; Leal and Spalding, 2022; UNFCCC, 2018).

While several studies in Kenya have shown that if mangrove systems are managed sustainably they provide both ecological and social benefits, there exist major challenges to sustainable management of mangroves across Kenya that would impact the MICP (Ahmed et al., 2023; Huff and Tonui, 2017; Riungu et al., 2022). These include overexploitation of wood products (County Government of Lamu, 2018; GoK, 2017), a lack of education around mangrove ecosystems, low community participation in the management of mangroves (Ahmed et al., 2023; Riungu et al., 2022) and the lack of funding directed to mangrove management efforts (Bosire et al., 2014). According to the Kenyan Forest Conservation and Management Act 2016 the core principles which guide the management of forests include good governance that works alongside public participation and community involvement (Ahmed et al., 2023). Further research suggests that for successful management of mangroves local communities must be part of the process due to their local ecological knowledge (Hamza et al., 2022; Huff and Tonui, 2017; Leal and Spalding, 2022). On a societal level, a study found coastal communities living near mangroves had a higher state of mental wellbeing than coastal communities who lived in a place where mangroves had been harvested and degraded (Ke et al., 2022). Indeed, Community-Based Mangrove Management has been recognised in the 2010 Kenyan constitution as well as in the Forest Conservation and Management Act 2016, a decision which aims to increase co-management of mangroves between communities and the Kenya Forestry Service (Hamza et al., 2022). Securing community involvement and support may be a challenge for the MICP as research conducted in Lamu through a series of interviews found over 70% of local residents disagreed with enforced policies and constraints for mangrove management and conservation (Ahmed et al., 2023). Despite the opposition to frameworks and policies, the same study also found community involvement would enhance conservation efforts and wider participation in governance standard setting for sustainable mangrove management and therefore must be prioritised.

The MICP could use carbon finance from the protected mangroves to support socially and ecologically sustainable management of the landscape, with a particular focus on community involvement and ensuring the system remains in a state of equilibrium. However, the aforementioned challenges will be present and in this context, regardless of whether the MICP registers as a blue carbon project, local community engagement should be considered an important factor to limit illegal harvesting and unsustainable degradation of the mangroves.

7. Limitations of research and observations for future work in this area

7.1. Dataset limitations

There are several limitations of the GMW 3.0 dataset used in this dissertation. Currently, there are very few global mangrove cover change datasets that provide an evaluation of classification accuracy and mangrove cover change varies dramatically amongst the available datasets (Hamza et al., 2022; Murray et al., 2022). The differences between the datasets can largely be put down to the use of different remote sensing devices and different methods of classifying the mangrove images (Murray et al., 2022). The authors of the GMW 3.0 dataset identified some of its limitations including some misregistration in the SAR mosaic datasets that were only able to be partially corrected and inaccurate classification in areas where the mangroves were fragmented, for example around aquaculture ponds (Bunting et al., 2022b). Furthermore, classification errors were also identified by the MICP personnel, who highlighted an area within the MICP polygon showing mangrove cover, where there only lies a sandbank. This area has the QGIS co-ordinates 4561904, -247326 and accounts for 3.5 ha of mangroves, representing 2% of total mangrove coverage across the MICP. This area of mangroves is only present in the 2019 and 2020 datasets, so is most likely a classification error. As it is a minimal amount of mangrove coverage, it does not significantly impact the validity of the previous results. In addition to this, another area was highlighted by the MICP personnel where the dataset showed no mangroves but according to the team there are an abundance of mangroves covering the area. As there is no data available for this area within the GMW 3.0 dataset it is not possible to quantify how many additional ha of mangroves may be present within the MICP. This error could result in a degree of underestimated mangrove cover, sequestration, carbon stocks and consequent income for the MICP through a blue carbon project. These classification errors highlight the importance and necessity of fieldwork to verify the dataset. Finally, as there is a gap of over ten years between the first year of data collection in 1996 and the second available year in 2007, should there be an inaccuracy in the 1996 data it would have disproportionate leverage over the other calculations. A future area of research should be to conduct fieldwork across the MICP to verify the remotely sensed data depicting mangrove coverage, particularly around the areas within the MICP where it was clear the data was inaccurate.

7.2. Carbon stock uncertainties

As this project was conducted remotely, there was not an opportunity to conduct fieldwork to verify the total ecosystem carbon held within the MICP mangroves or observe the entire ecosystem. Having a more detailed understanding of the local conditions can improve recommendations for successful restoration and protection of mangroves (Leal and Spalding, 2022) and therefore there will be some limitations in the data and subsequent recommendations. Furthermore, soil organic carbon often holds the majority of carbon in mangroves (Kairo et al., 2021; Riungu et al., 2022) and thus fieldwork should be conducted to measure the soil organic carbon stock within the MICP mangroves to verify the estimates in this paper.

7.3. Carbon project regulations and frameworks in Kenya

An area which must be prioritised for further research is the upcoming carbon credit regulations and frameworks in Kenya. In June 2023, the Kenyan Parliament proposed an amendment to the Climate Change Bill that specifically relates to any existing and future carbon projects within the country (GoK, 2023). Whilst the bill has not been passed at the time of writing, it includes new regulation of carbon markets that may have significant implications for the viability of a MICP blue carbon project. The new carbon market policy introduces the following changes to the voluntary carbon markets in Kenya. Firstly, the new bill would make it mandatory for all carbon trading projects to undergo Environmental and Social Impact

Assessments in accordance with the Environmental Management and Coordination Act of 1999, regardless of project scalability, which may not be financially feasible for the MICP. Secondly the bill would require every project to implement a community development agreement and a core and notable part of this includes an annual social contribution of at least 25% of the aggregate earnings to the community. The aim of this is to share any benefits from carbon markets with local communities and requires a proposed development plan for the communities around the project, which is overseen by the local county government (GoK, 2023). The parameters of the community development agreements have not yet been outlined, nor does the bill specify what or who constitutes as a local community which could cause ambiguity for the MICP. Finally, the bill would provide both the national government and county governments with the mandate to oversee and monitor agreement negotiations between communities and project developers. As corruption worries have been highlighted across other environmental projects in Kenya (Sovacool, 2021), this could be a deterrent for any future MICP mangrove projects and strong legal frameworks will be needed to mitigate against risk.

8. Conclusion

This dissertation estimated the carbon stock held within the MICP mangroves, determined the cover of mangroves and the changes in mangrove coverage throughout a 24-year observation period as well as analysed the economics of blue carbon markets to assess whether there is an opportunity for the MICP to form a blue carbon project using the mangroves. There are 169 ha of mangroves in the MICP, representing 16.9% of the total area. Mangrove cover across the MICP increased by 3% over the observed period in contrast to Lamu County, which saw a loss of 100 ha (0.3%). Using the calculations produced by Kairo et al (2021) on Lamu mangrove carbon stocks, the MICP mangroves are calculated to have an estimated above ground biomass carbon stock of 21,873.67 Mg C and an estimated total ecosystem carbon stock of 88,785.84 Mg C. Using the average carbon credit price for 2022 given by the World Bank, the total value of the mangroves within the MICP is estimated at of $568,299. Assuming a similar project structure to the Mikoko Pamoja project it is estimated the MICP could receive an annual income of $17,238. These findings suggest there is potential for a commercially viable carbon finance project using the MICP mangroves, contributing to sustainable conservation, and that the protected mangroves and any carbon finance gained from them can be used to support socially and ecologically sustainable management of the landscape. However, the extent to which this potential can be realised depends on a full baseline assessment, fieldwork calculations and Kenyan legislation and regulation.

Following the results from this paper, the following recommendations should be considered by the Manda Island Conservancy Project. First, fieldwork should be carried out to assess the validity of the dataset, with specific attention paid to the areas where the dataset was shown to be inaccurate. This fieldwork should include taking samples from the mangroves to determine the soil organic carbon, density of the mangroves and below ground biomass. Secondly, a full economic assessment should be undertaken, which includes the costs of the fieldwork, the upfront carbon project registration fees and any costs associated with the new Kenyan legal frameworks. This assessment, coupled with whether the MICP secures support from funders who would bring additional expertise to the project and help fund some of the upfront registration fees will help to validate the findings presented here regarding the commercial viability of carbon finance for the MICP mangroves. Thirdly, as mangroves provide a whole host of ecosystem services to the local communities, it is recommended that local community involvement is incorporated into any sustainable management plan to stem illegal harvesting and continued degradation of the mangroves. Finally, the Manda Island Conservancy Project should not act on implementing a blue carbon project until the new Kenyan legislation and accompanying regulation has been passed.

Overall, this dissertation project has provided an evaluation of the MICP mangroves and their potential to form the basis of a blue carbon project. It has quantified a baseline estimation of mangrove cover and carbon stock, discussed the evolution of local mangrove coverage patterns over time, explored and discussed the challenges facing mangrove conservation in Kenya and Lamu County, and highlighted the multifaceted nature of the voluntary carbon markets and the practicalities of creating a carbon project. The Manda Island Conservancy Project can use these findings to make an informed decision on whether to proceed with the formation a blue carbon project.

09. Data Availability Statement

The data collected for this dissertation is available from the Global Mangrove Watch 3.0 through their Zenodo link: **https://zenodo.org/record/6894273**. The code for processing and statistical analysis is available on GitHub, accessible via this link: **https://github.com/TESS-Laboratory/Shaw_dissertation_Manda_Island_Mangroves**

10. Supplementary Information

S1: Table documenting the step-by-step methodology that was used to download, process and analyse the datasets.

	Methodology
Step 1	Downloaded all the 11 years of vector data from the Global Mangrove Watch website.
Step 2	Uploaded the 11 years of vector data into QGIS.
Step 3	Uploaded the MICP boundaries polygon into QGIS and drew a polygon around the Lamu County.
Step 4	Using the geoprocessing tool in QGIS 'clip' each layer was clipped for both the MICP area and the Lamu County.
Step 5	Using the area tool on QGIS the area in sq metres was calculated for all data layers and then downloaded as CSV files.
Step 6	All CSV files were then uploaded into RStudio and saved within the R programme to ensure future accessibility.
Step 7	Once uploaded, R was used for each CSV to add an additional column drop unnecessary data, and rename the area column as 'Mangroves'.
Step 8	The datasets were merged to create two new data frames, one for the MICP data and one for the Lamu data. The sq meters were converted to hectares.
Step 9	Comparison bar charts and time series graphs were produced to show the difference in the two areas.
Step 10	A percentage change graph was produced (see Supplementary Information S3).
Step 11	R script was saved and backed up on GitHub (see data availability statement).

S2: Table highlighting a breakdown of mangrove coverage by year in both the MICP and Lamu County. Hectares have been rounded up to show an overall picture.

Year	MICP mangrove cover in ha	Lamu County mangrove cover in ha
1996	164	35,030
2007	166	34,869
2008	166	34,775
2009	166	35,024
2010	165	34,941
2015	165	34,807
2016	164	34,641
2017	164	34,764
2018	166	34,902
2019	170	34,976
2020	169	34,930

S3: Graph created in RStudio showing the percentage change in mangroves across the MICP and Lamu County compared to each previous observation year. For this graph the data from the 1996 year was removed because there was no year previously to compare it to, therefore the percentage change was inaccurate.

S4: Table showing the different methods and study areas of other carbon stock mangrove studies in Africa.

Location	**Methods**	**Total Area Studied**	**Authors**
Gabon	Remote sensing analysis and soil sampling.	96,302 ha	Trettin et al, 2019
South Africa	Field observations and soil sampling.	9.5 ha	Johnson et al, 2020
Madagascar	Remote sensing analysis and field observations including soil sampling.	1500 ha	Benson et al., 2017
Tanzania	Field observations and soil sampling.	410 ha	Alavaisha and Mangora, 2016
Global	Mangroves from 190 sites across 5 continents sampled.	Global observations	Kauffman et al., 2020

S5: Ethics information

About your dissertation

Completing the box below may help you to articulate – to yourself and your dissertation advisor – what your project is about, and what the research will involve. A screenshot of this initialled and signed page should be included in your project dissertation report.

You would be expected to complete this form before you carry out the bulk of your data collection and analysis. However, you can begin to explore research materials and datasets as you work to complete this form.

Summary of your dissertation research project
The aim of this dissertation project is to assess the potential for voluntary carbon markets to contribute to sustainable conservation at the Manda Island Conservancy in Kenya. Research questions include:

Q1: How much carbon is stored in the MICP mangroves?
Q2: How much carbon could the MICP mangroves sequester?
Q3: What has happened to mangroves in the MICP and the adjacent area over time?
Q4: How could protected mangroves in the MICP can support socially and ecologically sustainable management of the landscape?
Q5: Is it commercially viable for carbon finance from the mangroves at MICP to contribute to sustainable conservation?
Q6: What observations should be prioritised for future work in this area?

This dissertation will use data acquired from extensive analysis of land cover using free and open source software (FOSS) Quantum Geographic Information System (QGIS) and remote sensing (RS).
Questions 1, 2 and 3 of this dissertation projects will use RS and QGIS. These research questions will be addressed using both the Murray Global Tidal Wetland Change (1999-2019) and the Global Mangrove Forest Distribution (2000) datasets, alongside Landsat data which will be downloaded from Google Earth Engine. Questions 4, 5 and 6 will be addressed by a literature review of existing research papers focussing on Nature-based Solutions, the blue economy and carbon stocks within mangroves, and informant interviews with Permian Global.

Summary for any participants—what will taking part mean from the perspective of the participants?
Any participant interviews from Permian Global will be with experts and used to help inform the direction of my research and will be subject to the participant giving consent. As interviews will not be used to gather specific data for the dissertation, personal information will not be stored.

Summary of ethical issues, and how they will be managed.

Research: The dissertation project will not be using any datasets which have personal or private information referring to individuals. The datasets that will be used are open source and freely available to use for analysis on Google Earth Engine and will be fully referenced where required. The Tidal Wetland Change dataset was developed to support the conservation and management of the world's rapidly changing costal ecosystems and is free to use. The Global Mangrove Distribution dataset was produced by NASA which is available to use without consent from the provider. Data processing for this project will be done using open-source software (QGIS) to ensure transparency and accessibility. Throughout the research, I will also critique narratives that may be founded in post-colonial and Western thinking and focus on ensuring any language used is accessible and supports equality in society.

Participant involvement:
Any interviews conducted, will not be used to generate data for the project, but purely to inform the direction of research. I will ensure that informed consent is given ahead of any participant interview, and each interview will be done on a voluntary basis with the participant having complete choose whether they want to partake, and consent can be withdrawn at any point without any negative repercussions. Participants will know the purpose, benefits, and risks of the interview. Secondly, all participants will

GEOM146/7 Ethics Form Pack – 2023 11

remain anonymous outside of the study team comprising of the student and their supervisor, and no personal data will be collected or stored. Any notes from the interviews will be stored on an encrypted laptop and in my University of Exeter OneDrive, which is protected with two-factor authentication. Notes will be destroyed one year after submission of the dissertation.

Summary of measures taken to ensure research is in line with University Covid-19 guidance.
Any conversations with external participants to inform the direction of my research will be conducted online via Microsoft Teams to adhere to the University Covid-19 guidance.

Please note: All research requires consideration of ethical issues.

Student: I confirm that I have read and understood the material included in this form and agree to act ethically and in accordance with the requirements set out here.	
Student initials: AS	Date initialled: 21/04/23
Advisor: I confirm that I have reviewed this 'About your dissertation' page, and any participant information and consent sheets, that I have raised any issues needing correction or clarification, and that any issues have been addressed to my satisfaction.	
Advisor's signature:	Date signed: 25th April 2023

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