CARBON EMISSIONS FROM DEGRADED MANGROVES OF TUDOR AND MWACHE CREEKS, MOMBASA, KENYA

NYAMAO WYCLIFF NYAKUNDI

A thesis submitted to Graduate School in partial fulfilment for the requirements of the award of the Master of Science degree in Environmental Science of Egerton University.

Egerton University

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DECLARATION AND RECOMMENDATION

DECLARATION

I hereby declare that this thesis is my original work and has never been presented for the award of a degree in any University and that all the sources cited have been acknowledgement.

Signature... Date...

Mr. Nyamao, Wycliff Nyakundi

Reg. No. NM12/3384/12

RECOMMENDATION

This thesis has been submitted with our recommendation as University supervisors

Signature... Date...

Dr. George M. Ogendi

Department of Environmental Science,

Egerton University.

Signature.......... .... Date...

Dr. Jared O. Bosire

Kenya Marine and Fisheries Research Institute – Mombasa.

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ABSTRACT

Mangrove deforestation and degradation through anthropogenic activities accelerates climate change process. Carbon capture and storage in mangroves is about 3-5 times more per unit area than any vegetated ecosystem. Studies which experimentally determine differential emissions are globally limited and completely non-extent in Kenya. This study sought to establish the contribution of human activities on carbon emissions from mangrove ecosystems along the Kenyan coastline using two heavily impacted peri-urban creeks: Tudor and Mwache in Mombasa Kenya as a case study. Anthropogenic and natural drivers have subjected mangroves to wanton degradation. Stratified random sampling along intertidal transect with 10x10m plots laid 100m apart were used to collect vegetation and soil data.

The data was analyzed using EXCEL and STATISTICA version 8.0 software. The statistical analyses included descriptive data analysis, linear comparisons, ANOVA, and means comparisons using Tukey test. There were significant differences in ecosystem carbon ($p=0.005$) between highly degraded and less degraded sites within the creeks. Carbon emissions were estimated at $261.96 t.ha^{-1}yr^{-1}$ and $335.13 t.ha^{-1}yr^{-1}$ CO_2 equivalents for Mwache and Tudor respectively. The unprecedented high degradation rates, which exceed by far the national, mean and probably the global mean shows that the mangroves are highly threatened due to the discussed pressures. There is need to strengthen the governance regimes through enforcement and compliance and more capacity in mandated institutions e.g. NEMA, KFS, and community involvement e.g. CFAs to curb illegal logging and distilleries. Initiating restoration activities where natural regeneration has failed, providing residents with alternative and cheap sources of energy and building materials and enforcing a complete moratorium on wood extraction will allow recovery.

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LIST OF ABBREVIATIONS

AGB	Above Ground biomass
AGC	Above Ground Carbon
BGB	Below Ground Biomass
BGC	Below Ground Carbon
CI	Complexity Interval
D_{30}	Diameter at 30cm above the ground for dwarf mangrove species.
DBH	Diameter at Breast Height of Mature trees with Diameter $\geq$ 2.5cm
DMRT	Duncan’s Multiple Range Test
EPA	Environmental Protection Agency of the United States of America
FAO	Food and Agricultural Organisation
GHG	Greenhouse Gas
GPS	Global Positioning System
IPCC	Intergovernmental Panel for Climate Change
KMFRI	Kenya Marine and Fisheries Research Institute
LOI	Loss -on- Ignition
LSD	Least Square Deviation
MASMA	Marine Science for Management
SOC	Soil Organic Carbon
TOC	Total Organic Carbon
WIO	Western Indian Ocean
UNEP-WCMC	United Nations Environmental Programme World Conservation Monitoring Centre

CHATPER ONE

INTRODUCTION

1.1 Background Information

Mangrove ecosystems are located at the sea – land interface. Globally, there are at least 68 species of mangroves restricted to approximately 25°N and 25°S of equator and estimated to cover an area of between 180,000 and 200,000 km^2 (Spalding *et al.*,2010; Giri *et al.*, 2011). Although spatially limited, (covering 0.7% of the total tropical forests of the world) (Giri *et al.*, 2011), mangroves are keystone coastal ecosystems. They offer a considerable array of ecosystem goods and services. They offer critical ecological functions (Duke *et al.*, 2007), are centers of rapid C cycling (Bouillon *et al.*, 2008; Kristensen *et al.*, 2008) and have recently been found to rank among the most C-dense forests in the tropics due to deep organic-rich soils (Donato *et al.*, 2011; Kauffman *et al.*, 2011).According to Alongi (2012), mangroves sequester 14% of C in the oceans despite occupying less than 0.5% of the coastal ocean. This is mainly captured in the above ground and below ground vegetation components.

The biggest part which is up to 90% is captured and stored in the sediments (Bouillon *et al.*, 2008; Donato *et al.*, 2011; Kauffman *et al.*, 2011) showing that mangrove sediments have carbon storage potential. The rate of C storage in the sediments is approximately 10 times the rate observed in temperate forests and 50 times the rate observed in tropical forests per year (Laffoley, 2009). Overall, mangroves have a far greater capacity (per unit surface area) than terrestrial habitats to achieve long-term C sequestration in sediments, arising in part from the extensive below ground biomass burying approximately 18.4 Tg C per year (Laffoley, 2009).

Mangroves are being degraded at rapid rates globally with 1-2 % per year loss (Duke *et al.*, 2007; FAO, 2007). Primarily this degradation is due to over-exploitation and land conversion affecting organic soils to deep layers. As land use affects soils to deeper layers, the large C stores generate large GHG emissions when disturbed (Donato *et al.*, 2011).Since reducing C emissions will be a global concern for centuries, long-term C sequestration capacity must be accounted for in the benefits associated with mangrove restoration and protection.The large C- stores of mangroves end up generating large amount of GHGs (Donato *et al.*, 2011). Improved estimates of mangrove C storage have recently been obtained at global scales (Donato *et al.*, 2011; Kauffman *et al.*, 2011), but to date estimates of C emissions following degradation in Kenya are less studied hence the need for this study.

Despite its relatively small overall concentration in the atmosphere, CO_2 is an important component of Earth's atmosphere because it absorbs and emits infrared radiation thereby playing a role in the greenhouse effects. Naturally CO_2 in the atmosphere is re-absorbed by vegetation and therefore deforestation and land conversion reduces the valuable natural C sinks which helps to maintain a balance in the Earth's atmosphere. According to IPCC (2007), about 20% of global C emissions is directly contributed by deforestation and since mangroves store about 3-5 times more C per unit area than all known forest ecosystems, their continued degradation whose rates far exceeds that of tropical rainforests significantly contributes to elevated C emissions.

The effect of all this extra CO_2 in the atmosphere is that the overall temperature of the planet is increasing (global warming) on a day-to-day basis but the climate is changing in unpredictable ways (from floods and hurricanes to heat waves and droughts). Rising CO_2 concentrations are also likely to have profound direct effects on the growth, physiology, and chemistry of plants, independent of any effects on climate (Ziska, 2008). According to UNEP-WCMC (2006), 35% loss of mangroves over the past two decades resulted in release of large quantities of C aggravating global warming phenomenon. Unfortunately, studies monitoring C losses over longer periods, or the emission of other GHGs, are lacking (Bouillon, 2011**).**The forecasted consequences of climate change on ecosystems will be more severe if conservation is not given an upper arm as a strategy to mitigate GHGs emissions.

In Kenya, nine (9) identified mangrove species (Spalding *et al.,* 2010), distributed in six families and eight genera occur along the coastline (Kirui *et al.*, 2012). This is only 3% of the forest area in Kenya, or 1% of the total area of the country; which makes mangroves a scarce and very valuable resource (Kokwaro, 1985; Dahdouh-Guebas *et al.,* 2000).Over the years, Kenyan mangroves have been subjected to ever-increasing human population and economic pressure and degradation, which are directly reflected in increased coastal erosion, shortage of building material and firewood and reduction in fisheries (Kairo *et al.,* 2001). As forests are removed, the organic C built up over decades to millennia is subject to increased re-mineralization and erosion, and therefore to release to the atmosphere as CO_2 (Bouillon, 2011).

Recent detailed studies have indicated that some mangrove forests have suffered the highest ever-recorded losses of mangroves globally. Specifically, Mombasa mangroves comprising of Tudor and Mwache Creeks have suffered between 46 and 87% cover loss between 1992 and 2009 translating to annual loss rates of 2.7 – 5.1% (Adewole, 2012; Bosire *et al.*, 2014;

Kaino, 2012) far exceeding the global mean of 1 – 2%.The high degradation rates documented for Mombasa mangroves provided an opportunity to quantify C emissions due to unprecedented cover loss.

1.2 Statement of the problem

Mangroves sequester 14% of C in the oceans despite occupying less than 0.5% of the coastal ocean in the world. However, they are being deforested and degraded at rapid rates globally with 1-2% per year loss. Primarily this degradation is because of over-exploitation and land conversion which disturbs and exposes carbon stored in sediments leading to generation of large quantities ofGHGs.Information on deforestation, degradation, land-use change, and how they contribute to global anthropogenic CO_2 emissions is available. Past studies quantified total ecosystem C stocks but did not specifically assess the impact of deforestation on C emissions. Carbon emissions from these ecosystems are uncertain; due to lack of broad-scale data on C emissions thus the need for this study.The study sites (Tudor and Mwache) are facing pressures due to increased population and dependence on mangroves for life sustenance and effects of climate change, which have led to some of the highest globally recorded rates (2.7 – 5.1% p.a.) of mangroves loss.

1.3 Broad objective

To estimate C emissions from mangrove forests resulting from degradation in Tudor and Mwache creeks for mangroves management and conservation.

1.4 Specific Objectives

1. To estimateC stocks resulting from mangrove degradation within and between the two creeks.
2. To estimate C emissionsfrom mangrove degradation in Tudor and Mwache creeks.

1.5 Hypotheses

Ho_1: There is no significant difference in C stocks within and between Tudor and Mwache creeks.

Ho_2: There is no significant difference in C emission due to mangroves degradation in Tudor and Mwache creeks.

1.6 Justification

Mangroves offer a considerable array of ecosystem goods and services and critical ecological functions. Mangroves sequester 14% of C and store 3 – 5 times more C than any vegetated ecosystem. Mangroves have experienced the highest degradation rates, which are 7 times more than the tropical forests. Globally mangroves are degraded at 1 – 2% p.a. whileTudor and Mwache creeks have recorded the highest degradation rates of 2.7 – 5% p.a. (Adewole, 2012; Kaino, 2012). Carbon emissions from land-use change in mangroves are also not well understood. The fate of the below ground C is also understudied.While data exists on C stocks for different sites globally (Donato *et al.*, 2011; Kauffman *et al.*, 2011) and for the study sites (Adewole, 2012; Kaino, 2012; Mwihaki, 2012), data on differential emissions due to severe degradation is very limited and completely lacking in the Kenyan situation. The rate of C emissions following mangrove degradation will elucidate the impact of this loss in aggravating global warming and associated climate change effects. Estimating C emission is paramount as it gives a detailed analysis of C emissions and shows a linkage between anthropogenic activities, C emissions and climate change. The information is useful to mangroves managers, conservationists, and climate change experts, among others. It assists in forecasting and predicting the trends and addressing adverse environmental challenges facing the world concerning GHGs.

1.7 Scope and Limitations

The study was carried out in the mangrove forests of Tudor and Mwache creeks. The sites were selected based on the presence of widespread mangroves, die back areas due to natural process like *El-Niño* and high anthropogenic pressures due to the ever-increasing population from the adjacent informal settlements. The study focused on the assessment of the differences in C stocks in three carbon pools between the highly degraded and relatively less degraded sites and consequently estimated Cemissions. Although there was limited access to equipment for accurate field assessment of CO_2 emissions, general standardized protocol were used in estimation of CO_2 emissions.

1.8 Definition of terms

Anthropogenic – the human impact (influences) on the environment. It is the effect or the object on the environment resulting from human activity (IPCC, 2003).

Carbon sink – this is a natural or an artificial reservoir that accumulates and stores some carbon containing chemical compounds for an indefinite period.

Deforestation- The conversion of forest to other land uses, e.g. agriculture, and typically involves release of GHGs from loss of biomass and disturbance of the soil, dead wood and litter (Dargusch *et al.,* 2010).

D**egradation -** refers to changes within a forest, which negatively affect the structure or function of the forest, and its GHG storage capacity. Forest degradation practices include unsustainable commercial logging and over-harvesting of fuel wood and degradation is commonly a precursor to deforestation (FAO, 2006).

Global warming - the rise in the average temperature of Earth's atmosphere and oceans mainly by increasing concentrations of greenhouse gases produced by human activities such as the burning of fossil fuels and deforestation.

Greenhouse effect- a phenomenon whereby atmospheric gases with special physical properties (like carbon dioxide, methane and water vapour) help trap heat received from the sun, making the earth to be warmer than it could be otherwise.

Highly Degraded - The changes within the forest which negatively affect the structure or function of the stand or site, and thereby lowering the canopy to less than 40% (FAO, 2009)

Relatively Less Degraded - The changes within the forest which negatively affect the structure or function of the stand or site, and thereby lowering the canopy to about 80% (FAO, 2009).

Peri-urban- according to Hartel (2005), this is the transition zone, or interaction zone, where urban and rural activities are juxtaposed, and landscape features are subject to rapid modifications, induced by anthropogenic activities.

CHAPTER TWO

LITERATURE REVIEW

2.1 Mangrove ecosystem

Mangrove forests comprise trees and shrubby vegetation community that occupy the intertidal regions of the tropical and subtropical coasts worldwide approximately 25°N and S of the equator (Spalding *et al.*,2010). These are the only trees among a relatively small group of higher plants, which have been successful in colonizing the brackish waters or estuarine wetlands in intertidal zone (Tomlinson, 1986). Despite their small and limited area (≤ 0.7 % of tropical forests) they are of global economic, environmental and social importance to humans (FAO, 1994), and humans risk losing all these if necessary measures are not employed to curb the situation. Not only will the goods and services be lost, but also it will accelerate the effects and impacts of climate change whose consequences are far reaching.

Mangrove ecosystems occur due to complex interaction of various climatic and edaphic factors. Some of the evolved morphological and physiological specializations include; aerial breathing roots such as stilt or prop roots in *Rhizophora* spp.; pneumatophores in *Avicennia* spp.; knee roots in *Ceriops* spp. These assists in the ventilation of the buried portion of the root system that lies in the highly anaerobic sediment. Other adaptations include support roots and buttresses, high salt tolerance and salt secreting leaves of some species. Kairo (2010) observed that, the basic environmental requirements for growth and development of mangroves include; tropical temperatures above 20°C, protection from strong waves and storms, salinity, tidal flooding and nutrients exchange and a deep substratum for strong roots anchorage. In Kenya, mangroves have been estimated to cover 45,590 ha representing 3% of natural forests and 1% of the state land (Kirui *et al.*, 2012). These forests occur in creeks, protected bays and estuaries spread along the 600km coastline from Kiunga at the Kenya - Somali border to the North, to Vanga at the Kenya-Tanzania border to the South. Mangroves are good C sequestration agents storing enormous amount of C per unit area which can be lost if degradation continues.

Mangroves will often display horizontal distribution of species (Abuodha and Kairo, 2001), with certain species occupying the seaward fringes of swamps while others occur more commonly in the upland reaches, albeit with considerable overlap (Kirui, 2006). Such zonation has variously been attributed to tidal elevation, particle size characteristics and chemistry underlying, response to geomorphological factors, salinity and differential dispersal of propagules (Kirui, 2006).

2.2 Importance of mangroves

According to UNEP (2009), mangroves are among the main ecological habitats of the western Indian Ocean (WIO) region. The importance of mangroves can be summarised into ecological, economical and environmental uses as follows;

2.2.1 Ecological Importance

Ecologically mangroves provide nursery grounds for numerous fisheries (crabs and pelagic fishes), birds and many vertebrates and invertebrates **(**Abuodha and Kairo, 2001). The interlocking and complex prop roots, pneumatophores, and intertwined stems protect organisms from predators and harsh climatic and environmental conditions (Bosire *et al.*, 2014). Marine environment draws its nutrients from the dead decaying mangrove (Mwihaki, 2012) to support many food webs. Mangroves are prime nesting and migratory sites for many bird species due to the easy access to both food and resting area (Maikut, 2004). Odum *et al.,* (1982), reported 220 fish species, 24 reptile species, 18 mammal species, and 181 bird species that all utilize mangroves as habitats during some period of life. Other fish species use mangroves temporarily for foraging, roosting and breeding.

Mangroves prevent siltation of coral reefs and provide a sink trap for pollutants (Abuodha and Kairo, 2001), through its own process of filtering run offs and mixing of organic matter from the terrestrial ecosystems (Semesi & Howell, 1992). Reducing the pollutant sink increases their effects in the environment. Mangroves resilience to disturbances such as hurricanes, makes them self sustaining, protective barrier for human populations living in the coastal zones (Alongi, 2009). Mangroves are also a terrestrial tool as it stabilizes the shorelines. Maikut (2004) notes that, the mangrove "wall" between the land and the sea protects the shoreline from erosion and minimizes destruction from powerful waves.

2.2.2 Economical Importance

Mangrove ecosystem is a source of wood products – poles, timber, charcoal, non-wood products - salt, tannins, dyes (Mwihaki, 2012) and provides fishing areas for local communities. The rampart harvesting of mangroves to obtain the aforementioned products can be attributed partly to high cost of other forms of energy, construction material and in part to the reclamation of the rearward areas for coconut plantation(Bosire *et al.*, 2014). This releases unknown quantities of carbon to the atmosphere. Mangroves within the study sites are the main source of livelihoods for the surrounding community for a variety of uses including but not limited to: building materials, fuel wood, fodder, and fish, among others. The study sought to assess C stocks and emissions because of this degradation.

2.2.3 Environmental Importance

Mangroves exert a breakwater effect and absorb most of the energy from storm-driven wave action particularly when stands are high density (Abuodha and Kairo, 2001), hence helping to protect housing and farms inland (Wolanski *et al.*, 1992). They maintain and protect the coastal areas from extreme weather conditions and natural catastrophies by acting as buffers, thus minimizing the effects on the coastal ecosystems (e.g. 2004 Tsunami where vegetated areas were spared of the effects as compared with degraded areas (Dahdouh-Guebass, 2005; UNEP-WCMC, 2006). The extensive forests are important in oxygen production, carbon sequestration, water quality regulation, biodiversity habitats and maintaining the rearing and breeding grounds thus playing an important role for healthy coastal ecosystems.

According to Lovelock and Ellison (2007), mangroves can retain as much carbon as an estimate of 385 Mg C ha^{-1}within a range of 3.0 to 3.5 Mg Cha^{-1}yr^{-1}. Therefore, on issues of climate change, mangroves are well understood to trap and store enormous quantities of CO_2 from the atmosphere in their above and belowground biomass and sediments. Coastlines are protected from severe wave damage, shoreline erosion and high winds by mangroves canopy and prop roots. The prop root zone provides sessile filter feeding organisms such as bryozoans, tunicates, barnacles, and mussels with an ideal environment (Gilmore and Snedaker, 1993). As the ability of water to carry sediments depends on flow velocity, slowing the currents results in the sediments settling when the stand density is high thus helping to protect housing and farms inland (Wolanski *et al.*, 1992). These and more services will be lost including increasing the amount of carbon in the atmosphere if degradation is not controlled.

2.3 Threats to the mangroves

Mangroves are among the most threatened ecosystems on earth (Valiela *et al.*, 2001). Currently the annual decline rate of mangroves global scale stands at 1-2 % globallyreducing the mangrove forests to less than 50% of the original cover (Spalding *et al.*,2010) since 1990. This has remained 3-5 times faster than the overall global rate of deforestation (FAO, 2007). The major threats of mangroves include overexploitation due to demographic pressure from the swelling population in the adjacent informal settlements.Mohamed *et al.,*(2008) heighten that, peri-urban forests are prone to recurrent human pressures and thus environmentally stressed. The strength, attractiveness and durability of some mangrove species such as *Rhizophora, Heritiera, Bruguiera* and *Ceriops*, for poles, boats, housing, charcoal and non-wood products like tannins, have led to their massive extraction. The situation is worse in peri-urban mangrove areas like Tudor and Mwache, which are under pressure due to over-harvesting for domestic fuel-wood by the ever-increasing population (Omar *et al.*, 2008; Bosire *et al.*, 2014).

The poor or weak governance systems e.g. poor enforcement and compliance of the laws governing forest resources, have led to continued illegal extraction and widespread distilleries. The institutions mandated to enforce the law and implement the policy are weak or sometimes they are faced with conflicting legislation.Additionally, the conversion of mangrove areas to other land uses - aquaculture, agriculture, damming of rivers flow(Wolanski, 1992; UNEP, 1994; FAO, 2007) diversion of freshwater, saltpans have impaired the mangroves. The brine that is released from saltpans increases salinity in estuaries, especially during the dry seasons, causing stress in mangroves (Kigomo, 1991). Infrastructural development such as hotels, ports like LAPSSET have greatly reduced the mangrove areas. Pollution of the ocean waters from sewerage and Ocean oil spills are other threats to mangroves. In Kenya, the main source of petroleum products into the marine ecosystems is marine accidents like the oil spill at the Makupa cause way (Kairoet al., 2005). Oils spill effects are far reaching and remain persistent for a long period.

The effects of climate change e.g. sea level rise, flooding, sedimentation, cyclones (for southern Africa)affects not only the growth but also the areal extent of the mangroves. Like the 1997/1998 *El~nino* rains that led to increased sediment loading into the mangroves of Mwache creek thus smothering the roots system of the trees causing a massive die-back of the mangroves (Kitheka *et al.*,2003;2005). The greatest threat to loss of mangroves nowadays can be attributed to global climate change (CO_2 atmospheric concentration levels, changes in temperature, altered precipitation patterns, sea level rise) related effects as it threatens the survival of a diversity of species, humans and the integrity of ecosystems (King, 2004). Hitherto, the long-term impacts of climate related disturbances on mangroves remain unclear and there is need for a thorough understanding of mangroves vulnerability and resilience to climate driven disturbance at local, regional and global scale. These threats have led to a decline in the mangroves from 18.8 million ha in 1980 to about 15.2 million ha (FAO, 2006; Spalding *et al.,* 2010). This has led to wanton loss of biomass and consequently carbon emissions.

2.4 Roles of forests in climate change

The relationship between forests and climate change is unambiguous as the later affects the capacity of forest to provide their roles. According to the Kyoto protocol (1997), carbon sequestration through forests could contribute the lion's share of some parties' reduction commitment. Utilized to the fullest, forests will lower the global reduction commitment from 4% to about 1% of 1990 emissions during the first commitment period 2008 to 2012. However, degradation of tropical forest accounts for about 18% of GHGs emissions (IPCC, 2007) while in Africa degradation contributes about 70% of the total emission of GHGs (FAO, 2006). Forest degradation not only releases carbon into the atmosphere but also reduces the natural sinks that sequester excess CO_2 from the atmosphere. The capacity of mangroves to sequester CO_2 from the atmosphere has been recognized at an international level.

The provision of financial incentives to developing countries to reduce deforestation rates thus combating emissions was proposed in the REDD+ concept (IPCC, 2007). CO_2 exist in the atmosphere as part of the Earth's carbon cycle. It is the primary GHG emitted through human activities by altering the C cycle hence adding more CO_2 to the atmosphere or by influencing the ability of natural sinks, to remove it. While CO_2 emissions come from a variety of natural sources, human-related emissions are responsible for the increase in the atmosphere since the industrial revolution. Burning fossil fuels and deforestation and doing it so quickly that plants and trees that are alive now have no chance of soaking it up increases it in the atmosphere. The effect of all this extra CO_2 in the atmosphere is that the overall temperature of the planet is increasing (global warming).

2.5 Conceptual framework

Ecosystem processes are influenced by the human population through different enterprises. This process interferes with the natural biogeochemical cycles causing transformations and biotic alterations. This enhances the climate change processes leading to loss of biodiversity. In mangroves, species zonation, abundance, distribution, and productivity depends on disturbances they are subjected to. Severe disturbances lead to loss of ecosystem services thus affecting the environment and threatening human life. Release of CO_2 into the atmosphere aggravates climate change, with adverse impacts. New species of economic and ecological significance sometimes emerge. The impacts of severe disturbances may include wiping out some species and modification of the environment to unproductive form.

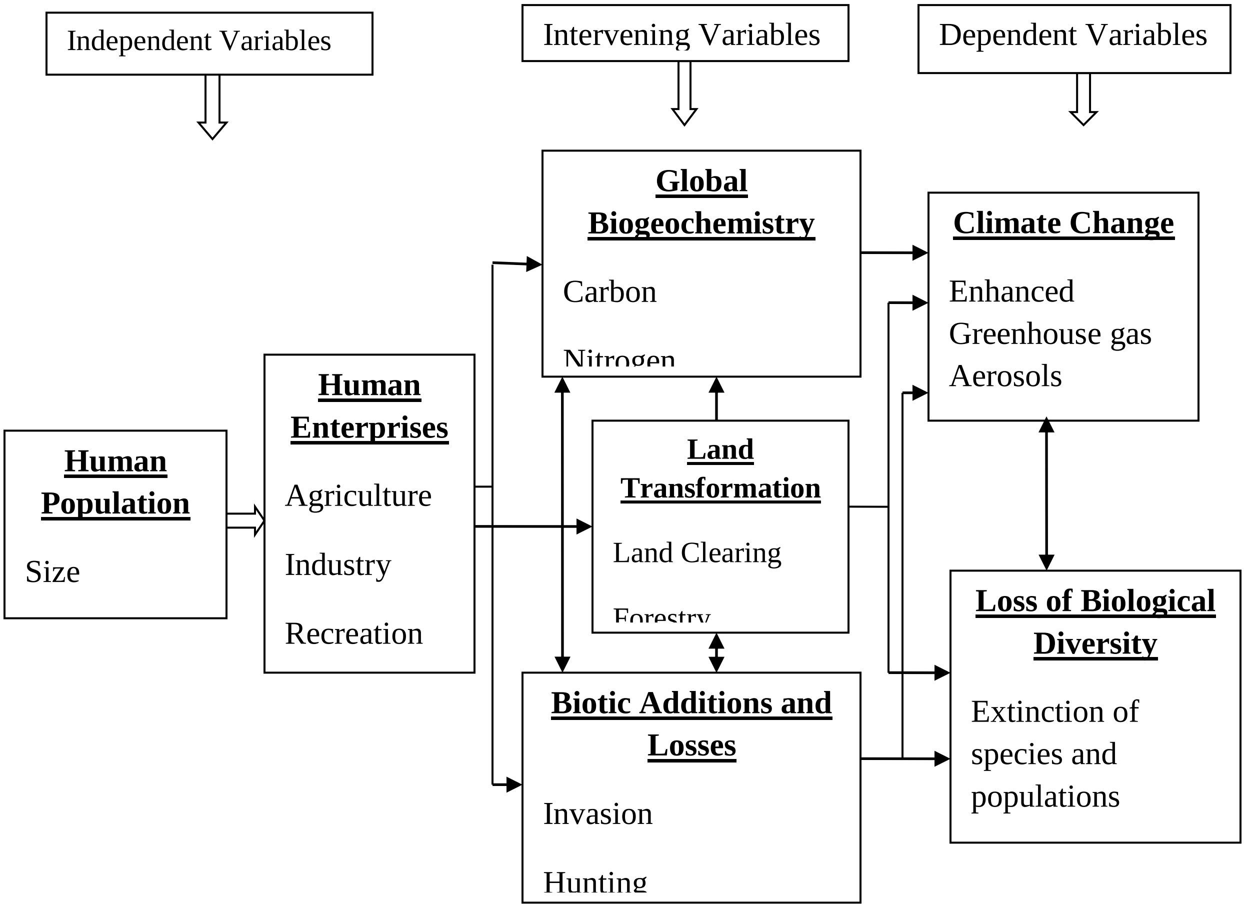


Figure 1: Conceptual framework of human enterprises influence on mangrove, their effects and reaction of the ecosystems. (Modified from Twilley, 1995)

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Description of the study area

This study was undertaken in Tudor and Mwache creeks in Mombasa. These are peri-urban creeks where mangroves have faced threats due to high population pressures, poor land use practices upstream and indirect impacts of climate change (Bosire *et al.*, 2014), making these mangroves record the highest annual degradation rates of between 2.7 – 5.1% p.a. (Bosire *et al.*, 2014). Tudor creek (4°2' S, 39°40' E) is located northwest of Mombasa and extends some 10-15 km in land. It has a surface area of approximately 20 km^2 at sea level and comprises of shallow channels, mud banks and mangrove forests (Mohamed *et al.*, 2008). It has two main seasonal rivers, Kombeni and Tsalu draining over 45,000 and 10,000 ha respectively (Bosire *et al.*, 2014) (Figure 2). Within the creeks, mangrove forest extends over an area of 1,641 ha, mainly composed of *Rhizophoramucronata Lamk, Aviceniamarina*(Forsk)and *Sonneratia alba*J. Smith., with no distinct zonation along the tidal gradient (Mohamed *et al.,* 2008).Sediments that are predominantly made up of mud and sand in some parts (Omar *et al.,* 2008) cover the forest.

Mwache Creek (4°3.01'S, 39.06°38.06'E), is located 20 km northwest of Mombasa (Figure 2). The total wetland area is approximately 1,500 ha with about 70% of the surface area being covered with mangroves comprising of both basin and riverine mangroves and a distinct mangrove-fringed channel in the lower sections (Mwihaki, 2012). The common mangrove species in Mwache are *Avicenia marina*, *Rhiziphora mucronata*, *Ceriops tagal* (Perr.) C. B. Rob., and *Sonneratia alba* (Kitheka *et al.*, 2002). The creek receives freshwater from seasonal Mwache River (Bosire *et al.,* 2006; Kaino, 2012). The rate of sediment production within Mwache River basin reaches a high of 3,000 tonnes per year due to poor land-use activities upstream, high rainfall intensity during the rainy season and steep land gradient (Bosire *et al.*, 2006).

3.1.1 Environmental and social-economic status of the study area

The climate within Tudor, Mwache and Kenyan coast is under the influence of monsoon winds creating two rainy seasons. Heavy rains occur during the South Eastern monsoon (March-May) and short rains during the North Eastern monsoon (October-November). Mean annual rainfall is 900mm with a great inter annual variability. Dry spell occur between January – February and August – September (Kitheka *et al.*, 2002). The Ocean waters are characterized with semi-diurnal tides having a tidal variation of about 4.0m and 1.8m within spring and neap respectively (Kitheka *et al.*, 2002). Temperature range between 24°C and 33°C with an annual evaporation of 1900mm. Relative humidity is high all year round with its peak during the wet period (Aura *et al.*, 2010).

The mangrove forest in the two peri-urban creeks is overstressed due to overexploitation (Adewole, 2012; Kaino, 2012; Kitheka *et al.*, 2002). Poor, uninformed, and unsustainable farming systems and practices in the areas have also led to mangrove vegetation degradation brought about by increased erosion that causes massive siltation and sedimentation (Bosire *et al.*, 2014; Kitheka *et al.*, 2002). The natural catastrophic phenomena of 1997-98 and 2006 El Nino (Bosire, 2010; Bosire *et al.*, 2014) also brought about the degradation of the mangroves.This was a period during which massive sedimentation and flooding for long periods was designated as the major cause of the mangrove dieback in many areas including Mwache (Kitheka *et al.*, 2002; Bosire *et al.*, 2006).

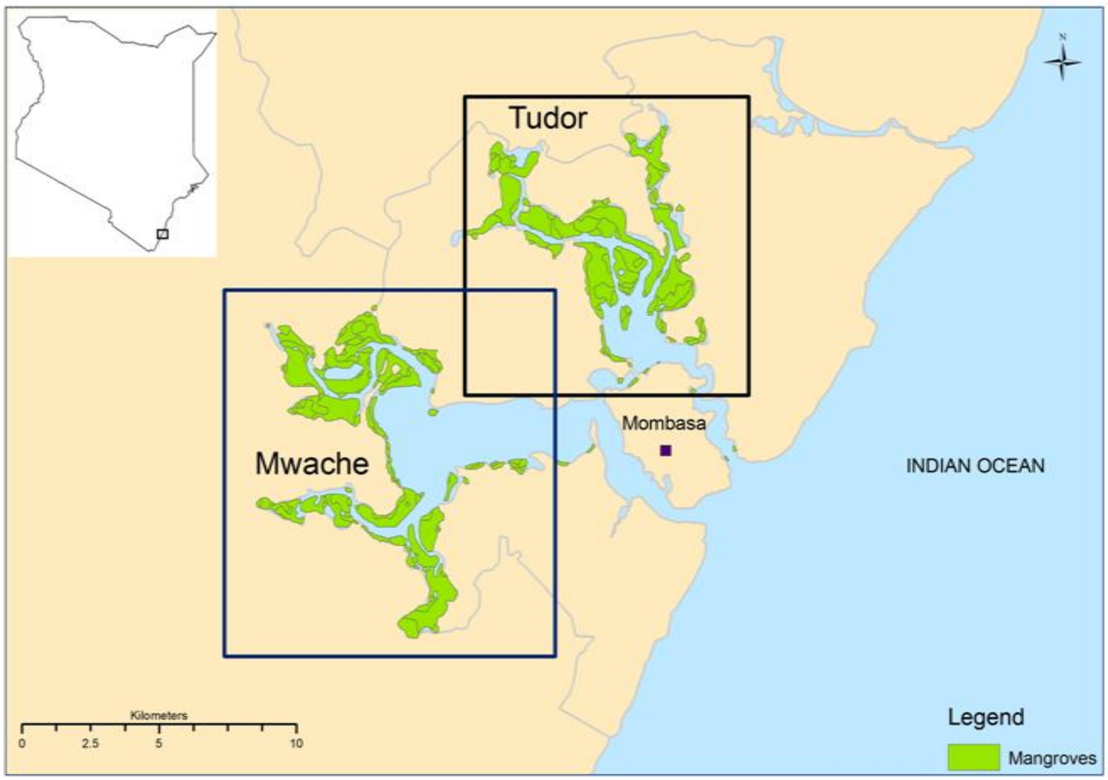


Figure 2: Mangrove areas of Tudor and Mwache creeks (Source: Bosire *et al.*, 2014)

The main social economic activities of Tudor and Mwache inhabitants are; subsistence farming, fishing, wood harvesting, charcoal burning which supports a population of about 50,000 persons (GOK, 2010). There is poor infrastructural development in the areas, with low class housing and lack of enough social amenities.

3.2 Sampling procedure

In both creeks, transects were laid in pre-selected highly degraded and relatively less degraded sections of the forest as an indicator of carbon emissions. Transects perpendicular to the shore were identified prior to field work using Google earth images based on the density of the vegetation and stand structure. Data was collected using stratified random sampling to avoid bias for three carbon pools (above ground, below ground and soils). Carbon from understory, litter and deadwood pools (IPCC, 2006; Kauffman and Donato, 2011), were not considered in the study as their contribution to ecosystem carbon was negligible (Donato *et al.,* 2011).

Plate 1: Highly degraded site of Mwache creek mangroves (Photo: Nyamao*et al.,* 2014)

In the mangroves, from the shoreline towards the mainland, 10 x 10m plots, approximately 100m apart were laid along intertidal transects in the highly degraded and relatively less degraded sites. Within the plots, trees with diameter ≥ 2.5 cm were identified; their heights (m) measured using *suunto* Hypsometer, diameter at breast height (cm) measured using forest calipers and recorded. Stumps were counted in each plot. Soil cores were obtained from the centre of the plot at low tide using a 7 cm diameter open-faced soil corer, sample sub-divided along the profile into 0-15 cm, 15-30 cm, 30-50 cm and 50-100cm. Sub-samples of 5cm height were taken from the mid section of interval. To avoid sample contamination, the sampling tools were cleaned after each sample collection. The samples were sealed, labeled and stored in the cool box at approximately 4^oC and taken to the laboratory for analysis. The GPS coordinates of the plots were recorded. Complexity index of sampled plots was calculated as a product of number of species, stand density, height and basal area.

$$CI = S*D*H*BA*10^{-5} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{..Eq. i}$$

Where: C.I – Complexity index

S – Number of species

D – Stand density

H – Mean height

BA – Basal area

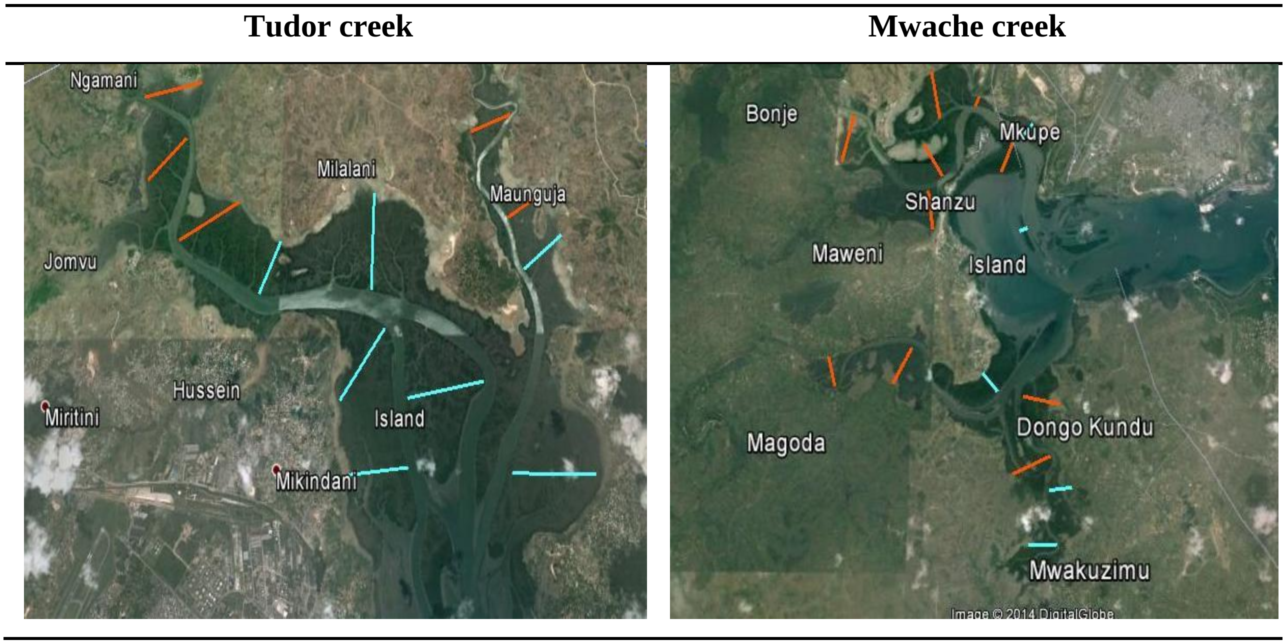

Tudor creek **Mwache creek**

Figure 3: Google earth sampling sites in Tudor and Mwache creek (Source: Nyamao *et al.*, 2015)

3.3 Biomass and carbon estimation

The above ground biomass (AGB) and below ground biomass (BGB) were estimated from data collected on the vegetation structure and the specific wood densities (ρ), using the general allometric equations developed by Komiyama *et al.*,(2005; 2008). The specific tree densities for the various mangrove species used were those generated from allometric work in Zambezi (Mozambique) mangrove forest which are within the Western Indian Ocean (WIO) region), (Bosire *et al.*, 2012). Total ecosystem biomass was obtained by summing up the biomass values per plot and averaging the values in all plots to get the average biomass in a site for both AGB and BGB. The total live biomass was obtained by adding both AGB and BGB in each site.

$$AGB = 0.251 * \rho * DBH^{2.46} \text{.......................................Eq. ii}$$

Where: AGB – Above Ground Biomass,

DBH- Diameter at Breast Height

ρ – Specific wood density

The above ground carbon was determined by multiplying the AGB by general wood C concentrations of 0.464 for all the species and 0.471 for *Sonneratia alba* according to Kauffman *et al.*, (2011).

$$AGC = AGB * 0.464 \text{……………………………………..Eq. iii}$$

The below ground biomass was determined using the general equations;

$$BGB = 0.199 * \rho^{0.899} * BDH^{2.22} \text{…………………………………….Eq. iv}$$

Where: BGB – Below Ground Biomass,

ρ– Specific wood density.

Carbon stocks in the below ground biomass was calculated as a product of C concentration with a default value of 0.39.

$$BGC = BGB * 0.39 \text{……………………………………..Eq. v}$$

3.4 Bulk density

The sediment samples collected were placed on pre-weighed crucibles and oven-dried to a constant mass at 60^{o}C and their weight recorded (Kauffman and Donato, 2012). To estimate soil bulk density (an indicator of soil compaction) the volume and the mass of oven-dried soil was used as illustrated below.

$$\text{Bulk Density } (gcm^{-3}) = \{\text{Mass of oven dried sample (g) / Vol. of sample } (cm^{3})\}\text{....Eq. vi}$$

3.5 Soil organic carbon analysis

The semi-quantitative method (that removes all the organic matter indiscriminately), of loss-on-ignition (LOI) was used to determine organic matter. The oven-dried samples used in bulk density analysis were homogenised by grinding using a mortar and a pestle and sieved using a 2mm sieve to remove debris. From each sample a pair of 5gram sub-samples, were taken and then set into a muffle furnace for combustion at 450^{o}C for 8 hours and then cooled before their weight were recorded again. Loss of soil organic matter (SOM) was noted as the difference in the mass of the soil before and after heating.

$$\text{SOM Content} = \{(\text{Initial weight} – \text{Final weight}) / \text{Initial weight (g)}\}*100\text{............. Eq. vii}$$

Total organic carbon (TOC) was worked and scaled up to obtain the carbon pools for the entire study site from a regression equation by Mwihaki (2012)

TOC (Mg Cha^{-1}) = {Bulk density (gcm^{-3})* Soil Depth Interval (cm) *%C}.......... Eq. viii

3.6 Carbon emissions

Due to degradation from both anthropogenic and natural drivers, an assessment was done to estimate carbon emissions. After estimating individual pools for each specific area, the C stock decreases in the three pools were calculated. Carbon emissions were worked using the C Gain-Loss and tier 2 method (IPCC, 2006). The estimates were worked out by getting the difference in C stocks between the highly degraded and the relatively less degraded between two different times. To estimate the rate of C stocks changes using the Gain-Loss and tier 2 methods, the equationbelow was used (IPCC, 2006).

$\Delta C = \{(C_{t2} - C_{t1}) / (t_2 - t_1)\}$ ....Eq. ix

Where:

ΔC = Annual carbon stock change in the pool, tonnes C/yr

C_{t1}=carbon stock in the pool at time t_1, tonnes C

C_{t2}=carbon stock in the pool at time t_2, tonnes C

Any net decrease in C stock was converted to the equivalent CO_2 emission by multiplying the net C stock change by 3.67 (stochiometric ratio of CO_2 and C) (IPCC, 2006).

CO_2 Emissions ($tha^{-1}yr^{-1}$) = 3.67 x Carbon stocks change…...........Eq. x

3.7 Data analysis

Data was analyzed using EXCEL and STATISTICA Version 8.0 to determine the relationship between mangrove degradation and C emissions. The difference in the amount of C between the study sites (highly degraded and relatively less degraded) was used to determine C emissions.To decipher any differences and relationships various statistical tools such as (ANOVA), regression analysis, correlations in addition to measures of central tendency and dispersion for biomass data was used. The statistical analyses included descriptive data analysis, linear comparisons, and means comparisons using Tukey test. Presentation of results was through graphs, scatter diagrams and boxplots.

CHAPTER FOUR

RESULTS

4.1 Stand structure and Biomass distribution

Four (Mwache) and five (Tudor) mangrove species were encountered at both the adult and juvenile stages.*Rhizophora mucronata* was the dominant species and was encountered at all sites except at the island, where *Sonneratia alba*dominated. The highly degraded sites in Tudor creek included Ngamani, Jomvu and North Maunguja while the relatively less degraded sites included Husein, Mikindani, Milalani, South Mikindani, Maunguja and the Island. For Mwache creek, the sites that were considered as highly degraded were Bonje, Maweni, Dongokundu, Magoda, Mkupe and Shanzu while the relatively less degraded sites included Maweni, Mwakuzimu, Mkupe and Island. In both creeks, sites were degraded to different degrees. To be able to estimate carbon emissions due to degradation effectively, comparisons were carried out between selected three highly impacted sites and three less impacted sites due to degradation as illustrated in tables and figures.

The highly degraded sites in both Mwache and Tudor creek had a low basal area, low mean height, low stem density and hence a low complexity index. The common species were almost the same in all sites. The highly degraded sites had the least mean structural characteristics and higher stump density (Table 1). Tukeys test showed a significant difference in height (Ht) ($p=0.0462$) amongst all the sites in highly degraded sites at Mwache creek. There was a significant difference ($p<0.05$) in basal area amongst tree species and amongst highly degraded and relatively less degraded sites. The highest basal area was witnessed at the less degraded site ($41.3 \pm 0.7 cm^2$), while the least was witnessed at the highly degraded site ($9.24 \pm 0.3 cm^2$) (Table 1). Tukeys' test showed no significant difference in tree height ($p=0.0845$) amongst all the sites in Tudor creek. The highest basal area was witnessed at Mikindani ($22.1 \pm 0.7 cm^2$), while the least was at Maunguja ($6.93 \pm 0.63 cm^2$) with a Tukeys' test showing a significant difference ($p<0.05$) amongst the sites. Along the shoreline, *Avicenia marina* was pronounced followed by *Rhizophora mucronata* then to the mainland *Ceriops tagal* dominated. *Sonneratia alba* was mainly encountered in the island or sites which were almost submerged. The highest stump density occurred in highly degraded site and least at the relatively less degraded site (Table 1).

Table 1: Structural characteristics(Mean±SE) of Mangroves at Mwache and Tudor creek

Parameter	**Highly Degraded sites**				**Relatively Less Degraded sites**			
Mwache creek								
Sites / C	Bonje	Dongokundu	Magoda	**Mean**	Maweni	Mkupe	Island	**Mean**
Species	2	2	2	**2**	2	3	2	**2**
Ht (m)	1.96±0.8	2.36±0.1	3.17±0.3	**2.49±0.4**	4.56±0.2	4.61±0.7	5.41±0.1	**4.86±0.3**
DBH (cm)	2.43±0.9	3.27±0.1	4.58±0.4	**3.43±0.6**	6.05±0.3	6.58±1.0	9.12±0.4	**7.25±0.9**
BA (cm^2)	4.64±0.8	8.41±0.1	16.5±0.1	**9.24±0.3**	28.8±0.1	33.9±0.8	65.42±0.1	**41.3±0.7**
Stem D.	1060±77	1500±186	1366±86	**1308**±81	2310±211	2520±261	2633±272	**2487**±251
C.I	0.19	0.60	1.43	**0.60**	6.07	11.8	18.64	**9.98**
Stump/ha	28.8±9.8	47.3±2.9	75.5±17	**50.5±13**	15±1.27	10.0±0.58	8.67±2.4	**11.2±1.9**
Tudor creek								
Sites / C	Ngamani	Jomvu	Maunguja	**Mean**	Husein	S.Mikindani	Mikindani	**Mean**
Species	3	1	2	**2**	3	3	3	**3**
Ht (m)	2.13±0.7	2.25±0.1	1.64±0.45	**2.0±0.19**	2.55±0.3	2.59±0.19	3.03±0.3	**2.73±0.2**
DBH (cm)	4.94±1.3	3.19±0.2	2.97±0.89	**3.7±0.62**	3.54±0.3	3.94±0.07	5.30±0.9	**4.26±0.5**
BA (cm^2)	19.2±1.2	7.9±0.1	6.9±0.63	**10.7±0.3**	9.87±0.1	12.2±0.00	22.1±0.7	**14.3±0.2**
Stem D.	525±31	1683±191	1022±121	**1076**±127	2533±261	3325±311	1925±212	**2594**±291
C.I.	0.64	0.30	0.23	**0.46**	1.91	3.15	3.87	**3.04**
Stump/ha	82.3±38	72.7±7.8	47±26.6	**67.3±10**	37±17.9	16±3.94	39±19.5	**30.7±7.4**

The mean live biomass in Tudor creek mangroves was estimated at 111.88±85 tha^{-1}, from AGB of 80.91±63 tha^{-1} and BGB of 30.97±22 tha^{-1}. The largest overall contributor of biomass was south Mikindani with 276.08±257 t ha^{-1} while the least was Maunguja with 12.15±7.22 t ha^{-1}. The highly degraded sites recorded the least mean biomass (26.6±6.1 t ha^{-1}) while the less degraded sites recorded the highest mean biomass (197.2±41 t ha^{-1}). Tudor creek biomass showed a significant difference (Tukey test) in AGB amongst the sites ($p<0.005$), and a significant difference ($p=0.004$) between the highly degraded and the relatively less degraded sites.

Mwache creek mangroves recorded a mean biomass of 148.71±117.21 t ha^{-1}, from AGB of 104.94±83.32 t ha^{-1} and BGB of 43.77±33.89 t ha^{-1}. The Island was the largest overall contributor of biomass (307.99±64.44 t ha^{-1}) which comprised 214.16±44.75 t $ha^{-1}$from AGB. Dongokundu was the least overall contributor of biomass (12.94±2.00 t ha^{-1}) which comprised

8.19±1.30 t ha^{-1} from AGB. The highly degraded sites recorded the least mean biomass (31.50±15.75 t ha^{-1}) while the less degraded sites recorded high mean biomass (265.92±31.26 t ha^{-1}) (Table2). Mwache creek also showed a significant variation in AGB between the highly degraded and less degraded sites (p=0.001). There was a significant difference (p<0.005) between the highly degraded and the relatively less degraded sites for BGB and total biomass. Across the various sites, there was a decline in biomass distribution from the shoreline through the mid section and towards the main land.

Table 2: Mangrove Biomass distribution(Mean±SE) in Tudor and Mwache creek during study

Parameter	**Highly Degraded sites**				**Relatively Less Degraded sites**			
Tudor creek								
Sites / C	Ngamani	Jomvu	Maunguja	**Mean**	Husein	S.Mikindani	Mikindani	**Mean**
AGB (t/ha)	10.7±5.3	18.8±11	23.7±4.3	**17.7±3.8**	129.8±99	204.7±99	97.8±74	**144.1±31**
BGB (t/ha)	4.96±2.1	8.65±4.5	13.1±2.3	**8.89±2.3**	49.2±33	71.4±64	38.5±26	**53.0±9.7**
TOT B (t/ha)	15.6±7.4	27.5±16	36.7±6.6	**26.6±6.1**	179±99	276±99	136.4±99	**197.2±41**
Mwache creek								
Sites /C	Bonje	Dongokundu	Magoda	**Mean**	Maweni	Mkupe	Island	**Mean**
AGB (t/ha)	12.3±0.28	8.19±0.07	44.3±1.07	**21.6±0.83**	147±1.35	203.6±3.8	214±0.75	**188.3±20**
BGB (t/ha)	6.41±0.15	4.75±0.03	18.5±0.39	**9.88±0.32**	57.8±0.47	81.4±1.35	93.8±0.29	**77.7±10**
TOT B (t/ha)	18.7±11.9	12.9±2.00	62.8±22.9	**31.5±15.8**	204.8±36	285±102	307.9±64	**265.9±31**

4.2 Bulk density

The mean bulk density for the mangroves of Mwache creek was 0.95±0.02 gcm^{-3}ranging between 0.71±0.01gcm^{-3} and 1.23±0.05 gcm^{-3}. There was a significant difference in the bulk density among the different sites along the depth profile (p=0.035). There was asignificant difference (p=0.005) in bulk density between highly degraded and less degraded sites (Figure 4), with the highly degraded having a higher bulk density. From the shore to the mainland along transects, there was a significant difference in bulk density (p<0.05) with the bulk density being high towards the mainland and lower along the shoreline.

The mean bulk density for the mangroves of Tudor creek was 0.85± 0.04 gcm^{-3}ranging from 0.64±0.02 gcm^{-3} to 0.92±0.03 gcm^{-3}. Tukeys' test showed no significant difference in the means of the bulk density amongst sites along the depth profile (0-15cm, p=0.260; 15-30cm, p=0.254; 30-50cm, p=0.134) but a significant difference between 50-100cm (p=0.035). There was no significant difference in bulk density between highly degraded and less degraded sites (Figure 4). From the shore to the main land along transects, there was no significant difference in bulk density (P>0.05).

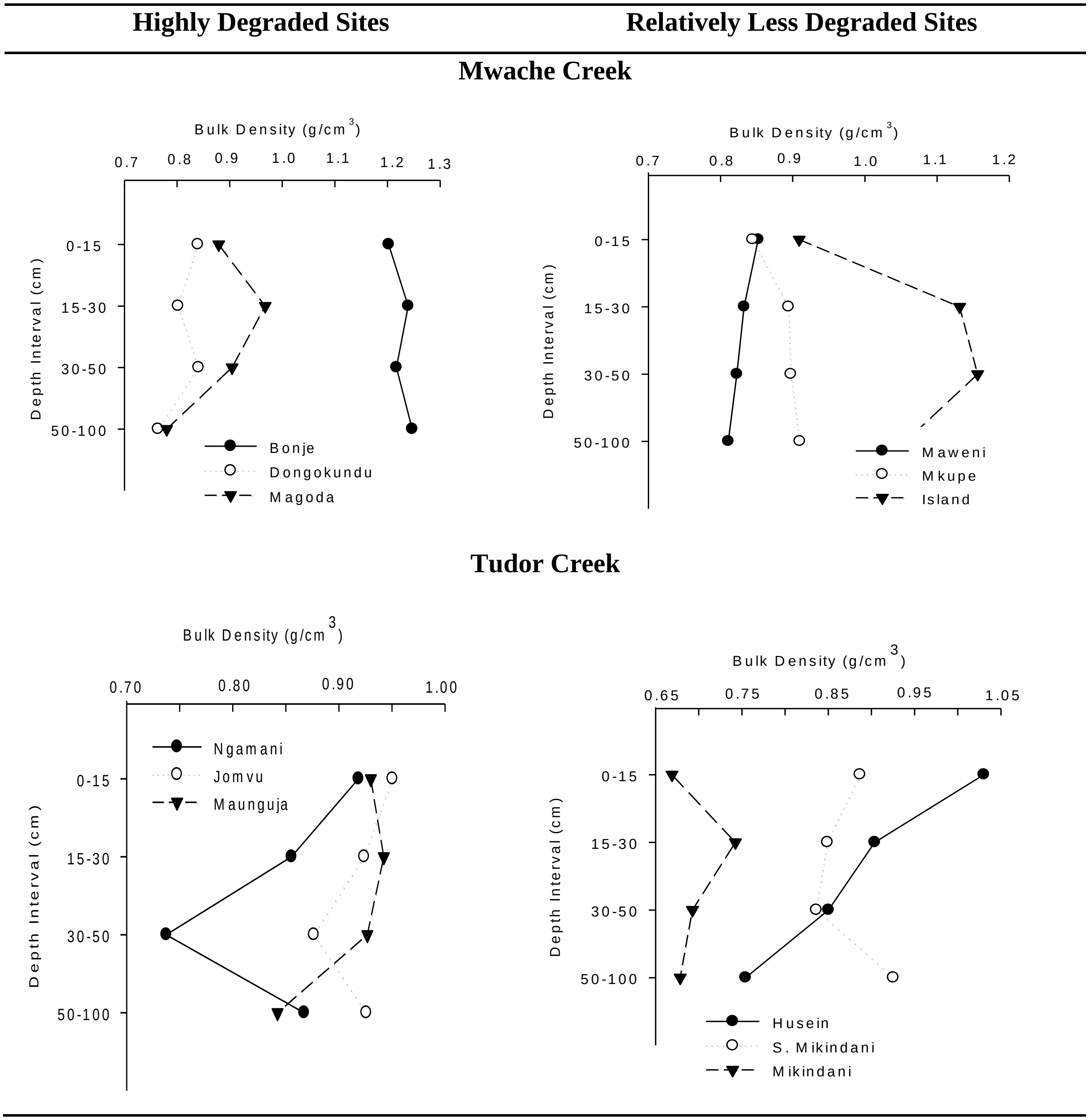


Figure 4: Soil bulk density along depth profiles in Mwache and Tudor creeks

4.3 Soil organic matter

The percentage SOM in the mangroves of Mwache creek was 4.39±0.01% ranging from 4.09±0.3% at Mkupe to 4.61±0.2% at Maweni. Tukeys' test indicated no significant difference (p=0.083) in percentage SOM within the creek. There was variation in percentage SOM in the deeper profile amongst sites with constant increase along the depth profile (Table 3). The mean percentage SOM was more in highly degraded sites (4.4±0.1%) and less in relatively less degraded sites (4.38±0.1%) with no significant difference (p>0.05). The SOM showed no distinct pattern along intertidal transects with no significant difference (p>0.05). The highly degraded sites showed less percentage SOM along the shoreline (4.26±0.2%) and the mainland (4.49±0.1%) but were relatively higher at the central section (4.57±0.2%). For the relatively less degraded sites there was a decline from the shoreline (4.61±0.2%), through the mid-section (4.32±0.1%) towards the landward areas (4.32±0.06%) in percentage SOM.

Table 3: Mangrove SOM (Mean±SE) along depth profiles in Tudor and Mwache Creeks

Highly Degraded sites					**Relatively Less Degraded sites**			
				Mwache creek				
Site/Depth	Bonje	Dongokundu	Magoda	**Mean**	Maweni	Mkupe	Island	**Mean**
0-15	4.48±0.2	4.52±0.2	4.55±0.2	**4.52±0.1**	4.41±0.1	4.17±0.1	4.17±0.1	**4.25±0.1**
15-30	4.64±0.3	4.22±0.1	4.09±0.1	**4.32±0.2**	4.23±0.1	4.75±0.3	4.63±0.1	**4.54±0.2**
30-50	4.18±0.1	4.46±0.1	4.25±0.1	**4.29±0.1**	4.52±0.1	4.44±0.3	4.45±0.1	**4.47±0.1**
50-100	4.63±0.3	4.49±0.2	4.31±0.1	**4.47±0.1**	4.37±0.1	3.96±0.4	4.48±0.2	**4.27±0.2**
Mean	4.48±0.2	4.42±0.1	4.29±0.1	**4.40±0.1**	4.38±0.1	4.33±0.1	4.43±0.1	**4.38±0.2**
				Tudor creek				
Site/Depth	Ngamani	Jomvu	Maunguja	**Mean**	Husein	S.Mikindani	Mikindani	**Mean**
0-15	2.67±0.2	6.08±0.9	5.51±0.5	**4.75±1.1**	6.76±1.3	5.17±0.7	7.54±1.4	**6.49±0.7**
15-30	3.43±0.4	10.2±3.2	6.91±0.8	**6.83±1.9**	7.00±1.6	7.08±0.5	8.62±2.7	**7.57±0.5**
30-50	4.03±0.3	6.84±0.8	6.78±0.6	**5.88±0.9**	7.16±1.8	7.76±0.8	7.74±0.7	**7.55±0.2**
50-100	5.35±0.8	7.71±0.8	6.86±0.7	**6.64±0.7**	7.49±1.1	5.45±1.1	6.97±0.5	**6.64±0.6**
Mean	3.87±0.3	7.69±1.1	6.51±0.5	**6.03±1.1**	7.10±1.4	6.36±0.3	7.72±1.3	**7.06±0.4**

The mean percentage SOM in the mangroves of Tudor creek was 6.55±0.52% ranging from 3.87±0.26% at Ngamani to 9.36±0.71% at Maunguja. There was a significant difference in percentage SOM within the creek (p=0.002).There was a significant difference between the highly degraded and relatively less degraded sites (p=0.004) within the top 0-15cm depth profile. There was variation in percentage SOM in the deeper profile amongst the sites (Table 3) with a significant difference (p<0.05). Percentage SOM was higher in relatively less degraded sites

(7.06±0.55%) and less in highly degraded sites (6.03±1.13%), however with no significant difference (p>0.05).

Table 4: Mangroves SOM (Mean±SE)along intertidal transects in Tudor and Mwache creeks

	Highly Degraded sites				**Relatively Less Degraded sites**			
				Tudor creek				
Site	Ngamani	Jomvu	Maunguja	**Mean**	Huseini	S.Mikindani	Mikindani	**Mean**
Sea	3.67±0.3	10.6±0.2	8.50±0.2	**7.57±2.0**	6.31±0.1	6.87±3.6	11.4±03	**8.19±1.6**
Mid	4.36±0.5	6.68±0.1	5.69±0.7	**5.56±0.7**	5.13±0.1	5.48±0.1	7.13±0.1	**5.91±0.6**
Land	3.24±0.1	4.45±0.4	6.41±0.2	**4.70±0.9**	9.87±0.3	6.74±0.2	6.09±0.3	**7.56±1.2**
Mean	3.75±0.3	7.23±0.2	6.87±0.3	**5.95±1.2**	7.10±0.1	6.36±1.1	8.21±0.2	**7.22±1.1**
				Mwache creek				
Site	Bonje	Dongokundu	Magoda	**Mean**	Maweni	Mkupe	Island	**Mean**
Sea	3.88±0.3	4.44±0.5	4.46±0.2	**4.26±0.2**	4.95±0.1	4.46±0.4	4.42±0.3	**4.61±0.2**
Mid	5.02±0.4	4.39±0.4	4.32±0.1	**4.57±0.2**	4.16±0.1	4.32±0.1	4.50±0.8	**4.32±0.1**
Land	4.77±0.1	4.41±0.4	4.32±0.3	**4.49±0.1**	4.38±0.2	4.21±0.1	4.37±0.3	**4.32±0.06**
Mean	4.56±0.3	4.41±0.1	4.36±0.2	**4.44±0.1**	4.49±0.1	4.33±0.1	4.43±0.2	**4.42±0.05**

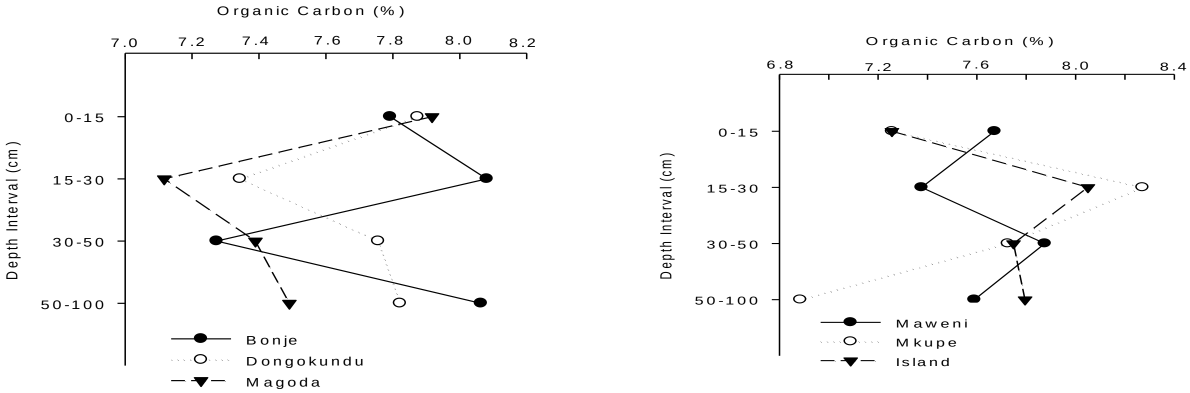
At Tudor creek, SOM showed no distinct patterns along the intertidal transectswith no significant difference (p>0.05). At the highly degraded site there was continuous decline in percentage SOM from the shore to the mainland with the shoreline having a higher percentage SOM (7.57±2.0%), followed by the central section (5.56±0.7%) and the mainland (4.70±0.9%). The relatively less degraded site showed no distinct pattern along transects.

4.4 Organic carbon concentration

Soil organic C concentration showed a wide variation in both Tudor and Mwache creeks. In Tudor the carbon concentration ranged from 6.73±0.45% (Ngamani) to 16.28±1.2% (Maunguja), with a mean of 11.39±0.9%C, while that of Mwache was between 7.12±0.46% (Mkupe) and 8.02±0.32% (Maweni), with a mean of 7.64±0.02%C (Figure 5).In both creeks, there was no distinct pattern in carbon concentration along the depth profiles. Tukey's test showed no significant difference in the concentration of SOC amongst the sites in both creeks (p>0.05). Tudor creek mangroves showed a significant difference (p<0.05) in C concentration between highly degraded and less degraded sites. Contrastingly, there was no significant difference (p>0.05) in carbon concentration between highly degraded and relatively less degraded sites in Mwache creek mangroves. In both creeks, along intertidal transects there was variations in the soil carbon concentration (SOC) concentration with a slight increase in the middle section and a decrease towards the mainland, but there was no significant difference ($p>0.05$) in SOC concentration.

Highly Degraded Sites | **Relatively Less Degraded Sites**

Mwache Creek



Tudor Creek

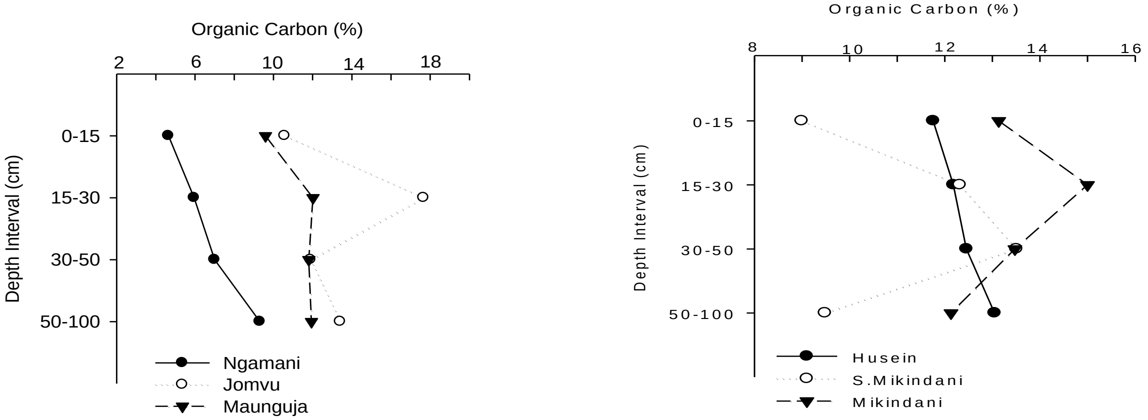


Figure 5: Distribution of Organic carbon concentration at Mwache and Tudor creeks during the study

4.5 Carbon pools

4.5.1 Vegetation pools

Tudor creek mangroves had a mean carbon of 49.29±37.7tha^{-1}comprising of 37.2±29.1 t ha^{-1} AGC and BGC of 12.1±8.61 t ha^{-1}. The largest contributor (S. Mikindani) had a mean of

122±114C t ha^{-1} while the least contributor was (Maunguja) with 5.29±3.23C t ha^{-1}. The highly degraded sites recorded the least mean C (11.62±2.65 t ha^{-1}) while the less degraded sites recorded the highest (86.98±18.34 t ha^{-1}) (Table 5). Variations were recorded in both AGC and BGC with a significant difference ($p<0.005$) between the highly degraded and the relatively less degraded sites. There was a slight significant difference ($p=0.048$) in the AGC between the highly degraded and the relatively less degraded sites. There was a significant difference in total C ($p<0.05$) between the highly degraded and the relatively less degraded sites.

The mean carbon in the mangroves of Mwache creek was estimated at 65.76±51.9 t ha^{-1} comprising of 48.69±38.6 t ha^{-1}AGCand BGC of 17.07±13.2 t ha^{-1}. The contribution was largest from Island (135.97±28.44C t ha^{-1})and least from Dongokundu (5.65±0.88C t ha^{-1}). The highly degraded sites recorded the least mean C (13.89±6.99C t ha^{-1}) while the relatively less degraded sites recorded the highest mean C (117.64±13.7C t ha^{-1}) (Table5). There was a significant difference in AGC amongst the sites ($p<0.005$), and a significant difference ($p<0.005$) between the highly degraded and the relatively less degraded sites. There was a significant difference ($p=0.042$) in the BGC between the highly degraded and the relatively less degraded sites and the same was witnessed in total C ($p<0.05$) between the highly degraded and the relatively less degraded sites. From the shoreline to the main land, there was a decline in carbon.

Table 5: Mangrove Carbon distribution(Mean±SE)in Tudor and Mwachecreeks during study

	Highly Degraded sites				**Relatively Less Degraded sites**			
				Tudor creek				
Sites/ C	Ngamani	Jomvu	Maunguja	**Mean**	Husein	S.Mikindani	Mikindani	**Mean**
AGC (t/ha)	4.91±2.45	8.66±5.44	10.9±1.99	**8.15±1.74**	59.7±47.1	94.2±88.7	44.9±34.2	**66.3±14.6**
BGC (t/ha)	1.94±0.82	3.37±1.76	5.09±0.89	**3.47±0.91**	19.2±13.2	27.8±25.2	15.1±10.2	**20.7±3.77**
TOT C (t/ha)	6.84±3.27	12.03±1.2	15.9±4.82	**11.6±2.65**	78.9±3.33	122±114	60.0±44.4	**87.0±18.3**
				Mwache creek				
Sites / C	Bonje	Dongokundu	Magoda	**Mean**	Maweni	Mkupe	Island	**Mean**
AGC (t/ha)	5.72±3.66	3.80±0.60	20.6±7.72	**10.0±5.30**	68.2±12.6	94.5±35.4	99.4±20.8	**87.4±9.67**
BGC (t/ha)	2.49±1.57	1.85±0.28	7.21±2.45	**3.85±1.68**	22.5±3.73	31.7±10.3	36.6±7.69	**30.3±4.12**
TOT C (t/ha)	8.22±5.23	5.65±0.88	27.8±10.2	**13.9±6.99**	90.8±16.3	126.2±45	135.9±28	**117.6±14**

4.5.2 Soil organic carbon

The soil organic C in the mangroves of Tudor creek was estimated at a mean of 52.34±2.05tha^{-1}. The least was from Ngamani (27.39±0.9C t ha^{-1}) while the highest was from Jomvu (67.87±1.6C t ha^{-1}) (Figure 6). There was a significant difference ($p<0.05$) in the mean SOC amongst the sites. There was no significant difference in SOC ($p>0.05$) between the highly degraded and the relatively less degraded sites. There was a steady increase in SOC along the depth profile in both the highly degraded and the relatively less degraded sites whereby 0-15cm depth interval had an average of 21.64±4.1C t ha^{-1}; whereas the 50-100cm depth interval had an average of 102.05±2.4C t ha^{-1} and they displayed a significant difference ($p<0.05$). There was a steady increase in SOC from the shoreline to the main land.

The SOC in the mangroves of Mwache was estimated at 180.38±4.67 t ha^{-1}. The least was from Maweni (135.02±3.88C t ha^{-1}) while the highest was from Bonje (242.59±87.03C t ha^{-1}) (Figure 6). The highly degraded sites had higher SOC (185.04±28.8 t ha^{-1}) than the less degraded site, (175.72±15.6 t ha^{-1}). There was no significant difference ($p>0.05$) in the mean SOC amongst the sites. There was a steady increase in SOC along the depth profile in both the highly degraded and the relatively less degraded sites with a significant difference ($p<0.05$).

4.5.3 Total organic carbon

Ecosystem C stock was estimated from the summation of the C storage in the three main pools that is; AGC, BGC and sedimentary carbon. The total ecosystem carbonstock in Tudor creek was estimated at 101.64±57.3C t ha^{-1}. This comprised of 37.22±6.3t/ha AGC, 12.08±0.2t ha^{-1} BGC and 52.34±2.05C t ha^{-1} SOC(Figure 6). The values show that the soil C contributed about 51% of the entire ecosystem C stock while AGC and BGC accounted for 37% and 12% respectively. The highest ecosystem C stock (173.96±7.5C t ha^{-1}) was estimated at S.Mikindani and the least (34.24±4.1C t ha^{-1}) was estimated at Ngamani (Figure 6).

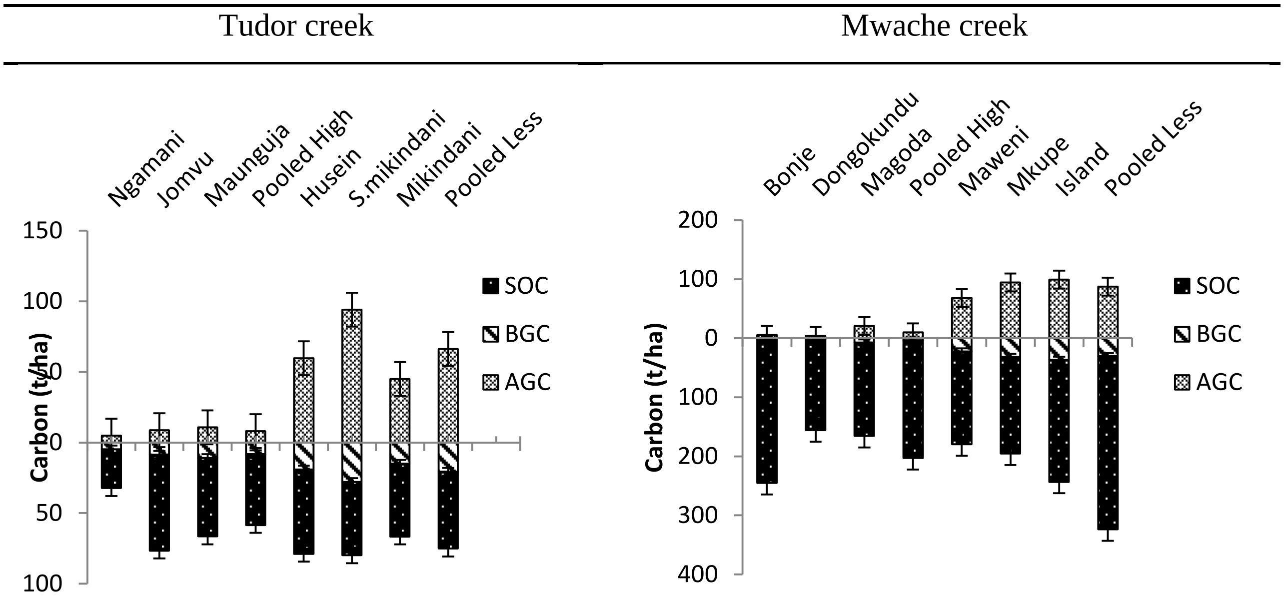


Figure 6: Ecosystem carbon pools (Mean±SE) at different sites in Tudor and Mwache creeks

The total ecosystem carbon stock in Mwache creek was estimated at 246.14±47.2t ha^{-1}. This comprised of 48.69±38.66t ha^{-1} AGC; 17.07±13.22t ha^{-1} BGC and 180.38±46.72C t ha^{-1} from the sediments (Figure 6). These values shows that the soil carbon contributed about 73% of the entire ecosystem C stocks while the AGC and BGC accounted for 20% and 7% respectively. The highest ecosystem carbon stock (342.59±21.9C t ha^{-1}) was estimated at the Island and the least (159.78±12.5C t ha^{-1}) was estimated at Dongokundu.

4.6 Carbon emissions

There were variations in different parameters between the highly degraded and the relatively less degraded sites in both creeks. In Tudor creek there was a 9.15% increase in bulk density between highly degraded and relatively less degraded sites. The highly degraded sites had a higher bulk density than the less degraded sites.Taking differences in carbon stocks between the highly degraded and the relatively less degraded sites then, 7.67 t ha^{-1} AGC, 0.53t ha^{-1} BGC, 99.52t ha^{-1} sediments C and total of 91.32C t ha^{-1} (Table 6) were lost. This translates to a percentage loss in C of35% AGC, 4.8%, BGC, 40% sediments and a total C loss of 32%.From Adewole (2012) the carbon stock for Tudor was 284.27±16.85t ha^{-1}. This study estimated C stocks in Tudor at 101.64±57.3t ha^{-1}. The carbon stock change within the two years period in Tudor creek mangroves was 183.63t ha^{-1}. The rate of C emission from Tudor was estimated at 91.32tha^{-1}yr^{-1} which translates to 335.13 t ha^{-1}yr^{-1} CO_2 equivalents

In Mwache creek, there was a 1.66% increase in bulk density between highly degraded and relatively less degraded sites with the highly degraded sites having a higher bulk density. Taking differences in carbon stocks between the highly degraded and the relatively less degraded sites, 29.41t ha^{-1} AGC, 9.06t ha^{-1} BGC, 32.86t ha^{-1} sediment C and a total of 71.38C t ha^{-1} (Table 6) were lost. There was a great percentage loss in C with the AGC losing up to 27%, BGC losing 26% and a total C loss of 18% annually. From Mwihaki (2012), the carbon stock for Mwache was 388.9±63.2t/ha. This study estimated C stocks inMwache at 246.14±47.2t ha^{-1}. The carbon stock change within that period of two years in Mwache creek mangroves was 142.76t ha^{-1}. The rate C emission from Mwache was estimated at71.38 t $ha^{-1}yr^{-1}$, which translates to261.96 t $ha^{-1}yr^{-1}$ CO_2 equivalents.

Table 6: Mangroves C emissions(Mean±SE)in Tudor and Mwache creek during the study

Carbon Pools	C. Stock 2012	C. Stock 2014	C. Stock Change	Emission t/ha/yr	% Annual C. Loss	**CO_2 Equivalents**
			Tudor creek			
AGC	21.88±3.38	37.22±6.3	15.34	7.67	35.05	**28.15**
BGC	11.02±4.04	12.08±0.2	1.06	0.53	4.81	**1.95**
SOC	251.37±9.07	52.34±2.05	199.03	99.52	39.59	**365.22**
TOC	284.27±27	101.64±57.3	182.63	91.32	36.78	**335.13**
			Mwache creek			
AGC	107.5±14.8	48.69±38.66	58.81	29.41	27.36	**107.92**
BGC	35.2±4.3	17.07±13.22	18.13	9.06	25.74	**33.27**
SOC	246.1±71.5	180.38±4.67	65.72	32.86	13.35	**120.59**
TOC	388.9±63.2	246.14±47.2	142.76	71.38	18.35	**261.96**

The comparison between the highly degraded shows high carbon emissions (Table 7)

Table 7: Carbon emissions(Mean±SE) from degraded and less degraded Mangrove sites

Carbon Pools	Less Degraded	Highly Degraded	Carbon Stock Change	**CO_2 Equivalents**
		Mwache creek		
AGC	87.35±9.66	10.03±5.30	77.32	**283.76**
BGC	30.29±4.12	3.85±1.68	26.44	**97.02**
SOC	185.04±5.15	175.71±9.54	9.33	**34.25**
TOC	293.35±18.93	198.93±16.53	94.42	**346.53**
		Tudor creek		
AGC	66.87±7.65	8.22±1.30	58.65	**215.25**
BGC	20.69±2.11	3.47±1.42	17.22	**63.20**

CHAPTER FIVE

DISCUSSIONS

5.1 Stand structure and Biomass distribution

Different factors played a role in determining stand structure for the Mombasa mangroves under study. *Rhizophora mucronata* was encountered at all sites and was the dominant species may be due to its capacity to regenerate easily and high tolerance to disturbances, ability to colonize inundated substrates (Lovelock, 2005) and its large propagules mass withstanding siltation (Mohamed *et al.,* 2008). This was not the case in the Island where *Sonnerati alba* dominated due to preference to prolonged submergence and low salinity (Tomlinson, 1986). There was no distinct zonation along intertidal transects in Tudor creek, similar to findings by Adewole (2012) which was also supported by Mohamed *et al.,* (2008). There was a variation in the stand characteristics along the inter-tidal transects with the central section having well developed stand structures as manifested in height and diameter. This could be correlated with variation in soil physico-chemical characteristics and variation in salinity (Lovelock, 2005). Distribution and spatial patterns in natural mangroves stand are linked to variation in edaphic and environmental factors, predation by understory organisms and tolerance to disturbances (Bosire *et al.,* 2005; Mckee *et al.,* 2007).

Along the shores juveniles (harvested from inside parts) are stacked and collected using boats during high tides (Plate 2). The high degradation has reduced the mature trees significantly and currently the harvesters are cutting the juveniles. In some cases large trees sometimes with cut tops were often encountered along the shores, which were left probably because of protection of the coastline, sign of natural ingenuity in the local inhabitants as also observed byAdewole (2012). The poor stand structure witnessed at the shores and towards the mainland could be due to ease accessibility.Conversely the better stand structures at the central section and the island could be attributed to poor accessibility by woodcutters, availability of more nutrients and reduced impacts by land based processes (e.g. sedimentation) which have decimated mangroves in vast areas (Kaino, 2012). The poor performance of the trees towards the mainland can be attributed to low nutrients availability, high salinity, high sedimentation due to poor land use practices and accessibility due to proximity to the village, leading to stunted growth (Adewole, 2012). Stand structure is a reliable indicator of forest development (Kairo *et al.,* 2002) and mangrove stand structure has a direct bearing on carbon stocks.

Plate 2: Young*Rhizophora*harvested along Tudor creek (Photo: Nyamao*et al.,* 2014)

The pronounced human activities in the nearby farming areas have led to increased high sediment deposition evidenced by shallow sandy soils and large mudflats.Highly degraded sites had a high stump density due to over harvesting (Table 2and Plate 1), but was not a general case.Sites, which experienced the massive die back due to the Indian Ocean Dipole, were degraded but had less stump density. Anthropogenic influences (indiscriminate and unregulated harvesting, raw domestic sewage discharge and enhanced siltation) have had cumulative effects on stand structure and regeneration of forest. This has resulted to characteristically high stump density and dominant crooked tree form (Mohamed *et al.*, 2008).

Total available biomass depends onthe species, stand structure, and prevailing environmental conditions. The many small trees in Mwache contributed less to overall biomass. Young stands have less accumulated biomass compared to older stands (Mokany *et al.,* 2005). In both creeks, highly degraded sites had the least biomass due to overexploitation but Mwache had a higher biomass than Tudor due to the differences in pressure intensity (Bosire *et al.,* 2014).

Due to its close proximity to informal settlement, Tudor creek experiences higher rates of overexploitation. Again, the differences in biomass can be attributed to the differences in environmental conditions as they control variation in forest structure (Lovelock, 2005). Species that grow in frequently inundated sites had a higher biomass than those that thrive in landward edges (Kaino, 2012). This is because of increasing salinity along intertidal gradient (Saintilan, 1997) and poor nutrients, dry ground (Tommervic *et al.,* 2008) accompanied with sedimentation.

The AGB for Mwache (Table 3) was much below that which was recorded by Kaino (2012), (229.38±53.28 t/ha), which could be attributed to continued harvesting and poor regeneration, but falls within the ranges of 6.8 to 460 t/ha which was reported in a review of tropical mangroves (Saenger and Snedaker, 1993; Komiyama *et al.*, 2008).

5.2 Bulk density

The bulk density in Mwache varied greatly with a decline along depth profile up to one meter. This could be attributed to increased degradation and decomposition of the vegetation due to climatic change associated phenomena and compaction with time. These figures agree with the findings of Donato *et al.,* (2011) in Indo-Pacific region and Ceron-Breton *et al.,* (2010) in their study in Mexico. In Tudor creek, the bulk density showed no clear pattern along depth profile. According to Mwihaki (2012), the observed fluctuations in the bulk density in mangroves with no clear trend along depth profile may be because of the varying vegetation density, the morphology and the heterogeneity in the rooting systems. The bulk density did not differ significantly along inter tidal gradient, results, which are in line with the findings of Donato *et al.,* (2011) due to compaction from sedimentation.

Due to the effects of climate change and uncontrolled human pressures accompanied with poor and uninformed farming systems along the creeks, there has been increased sedimentation, which directly alters the bulk density (Bosire *et al.,* 2014). Exposure to direct sunlight consequent to canopy disturbance also leads to high rates of water loss and thus more compacted sediments.Sites, which faced natural pressures, had a slightly lower bulk density as compared to sites, which faced anthropogenic disturbances due to biomass transfer. The continued subjection of these sites to pressures, which cause a lot of sedimentation and reduced floral and faunal activities, reduced roots network and microbial activities, reduces the soil air spaces, increases compaction thus leading to high bulk density (Adewole, 2012). It is expected that a well-structured soil would have a low bulk density, which generally increases with depth (Adewole, 2012). The lower the bulk density, the better the soil aeration and inherent conditions for edaphic life and nutrient turn-over (Haekansson and Lipiec, 2000). Mangrove soils consist of a variably thick, tidally submerged suboxic layer supporting anaerobic decomposition pathways and having moderate to high C concentrations (Donato *et al.,* 2011).

5.3 Soil organic matter

The percentage SOM was higher at the shores but reduced steadily towards the main land. This could be attributed to poor forest structure towards the mainland. High SOM contents in mangrove soils is due to long periods of tidal flooding and low decomposition rates sustaining anoxic conditions (Ceron-Breton *et al.*, 2010). The availability and composition of percentage organic C buried in the mangroves forests is highly dependent on the prevailing environmental conditions (Kristensen *et al.,* 2008) and the interactions with adjacent environments leading to exchange of materials between these environments (Kitheka *et al.,* 2005; Bouillon *et al.,* 2008; Kristensen *et al.,* 2008). According to Bosire (2010), site conditions have a great bearing on natural regeneration and overall vegetation growth hence the observed high organic matter at degraded sites may be attributed to the decomposing litter after degradation.

Greater burial of C was expected in the sea ward and land ward zones due to the prevailing high percentage silt and clay and low bulk density (Mwihaki, 2012), but did not occur as expected may be due to the washing off of the organic matter in the seaward zones(Alongi *et al.,* 2005). The varying conditions also explain the discrepancy in the spread of SOM. According to Santo *et al.,* (2011), the accumulation process of organic matter is enhanced in the mid-forest zone where the drainage may be deficient compared with the seaward zone. The less organic matter content towards the mainland could be attributed to the rising salinity caused by infrequent tidal inundation (Kitheka, 2002; Bouillon *et al.,* 2007); the poor stand structure, or continued siltation due to poor farming systems on the adjacent farms. In areas where the organic C was high towards the landside could be attributed to the deposition from external sources.

The highly degraded sites had low percentage organic matter than the relatively less degraded sites in Tudor (Table 4) a factor that could be attributed to stand structures driven by both natural and anthropogenic processes. In Mwache, the difference was negligible and may be attributed to intensity of the pressure they are exposed to. Mangrove degradation increases the rate of soil decomposition hence reduced organic matter content (Ceron-Breton *et al.,* 2011; Donato *et al.,* 2011; Lovelock *et al.,* 2011).

5.4 Organic carbon concentration

Along intertidal transects there were variations in the SOC concentration with a slight increase in the middle section and a decrease towards the mainland, analogous to previous results in Palau, Tudor and Mwache (Kauffman *et al.,* 2011; Adewole, 2012; Mwihaki, 2012). The high

SOC concentration in the central section may be due to good stand structure, reduced wave action, more deposition, reduced wash and salinity. There was no significant difference in SOC concentrations between highly degraded and relatively less degraded sites in Mwache creek may be due to limited differences in stand structure. According to Mwihaki (2012), the current structural state and the relatively low values of SOC in the forest are an indication of loss of previously buried C from the area. Mwache lost less cover than Tudor which lost 87% of its mangrove cover (Adewole, 2012; Kaino, 2012).The significant difference in SOC concentrations between the highly and relatively less degraded sites in Tudor creek isdue to intense pressure thus greater mangrove loss. It has widespread illegal distilleries, which have decimated the mangroves.

5.5 Carbon pools

On both creeks, the relatively less degraded sites had a higherC than the highly degraded sites (Figure 6). The high C in the less degraded site is attributed to the good stand structure. On both creeks there was a steady increase in organic carbon along depth profile and may be attributed to compaction with time (Adewole, 2012; Mwihaki, 2012). Conventionally, the BGB is approximately 50% AGB and the patterns are not strange. The carbon variations experienced with distance from the shores to the mainland may be due to reduced activities towards the mainland and massive sedimentation. The results of this study show marked differences in C distribution in various sites within the mangroves, with higher values less degraded sites. The variations are due to different climatic conditions, management conditions, environmental stress, age, forest type and intensity of pressure (Twilley *et al.,* 1992; Kristensen *et al.,* 2008). This is in agreement with past studies that mangrove sediments are viable site for organic C storage (Ceron-Breton *et al.,* 2011; Donato *et al.,* 2011; Kauffman *et al.,* 2011).

Total C was higher in Mwache than Tudor creek may be due to intense pressure experienced by Tudor due to its proximity to the village whereby up to 87% of mangroves were lost (Adewole, 2012). Although highly degraded, Bonje in Mwache creek had the largest overall carbon (242.59±87.03C t ha^{-1}) a factor attributed to the high C in the sediments due to the natural die back. AGC and BGC amongst the sites in Mwache creek was less probably because of the poor distribution of vegetation.Global climate change working synergistically with increased anthropogenic factors threatens the resilience of mangroves (Kitheka *et al.,* 2002; Bosire *et al.,* 2006; McLeod and Salm, 2006) as they are the most prominent ecosystems in the low lying coastal areas of the tropics. This leads to more loss of carbon resulting to increased temperatures, changing hydrologic regimes, rising sea level, increased coastal erosion, sedimentation and increasing frequency and intensity of storms and above all increased CO_2 levels (Field, 1995; Gilman *et al.,* 2008). Kirui *et al.,* (2012), notes that given the global mangrove cover of 170,000 Km^2 the total amount of C sequestered by mangroves is approximately 25.5×10^6 t Cyr^{-1}. This suggests that the persistent anthropogenic and natural disturbance reduces significantly the sequestration potential of the mangroves as exemplified by reduced C stocks estimates.

5.6 Carbon emissions

Estimating degradation and land use emissions in mangroves is a useful exercise, but is made difficult by paucity of data on BGC storage in most regions which includes combined data on C concentrations, bulk density and depth as well as land use change effects on C pools (Donato *et al.,* 2012). There was higher C emissionsin Tudor than in Mwache a factor attributed to intense pressure exerted through direct and acceleratedbiomass removalin Tudor. The informal settlement in Tudor draws energy in form of fuel wood from the mangroves apart from the widespread distilleries. The difference in C between the highly degraded and the relatively less degraded sites showsaggravated carbon emissions.Much more will be released if conservation measures are not adopted and implemented effectively. From the shores towards the mainland there was an increase in C up to the central section but declined towards the mainland and this could be because of good stand structure at the central section due to poor accessibility, good environmental and edaphic factors. Conversely, less carbon towards the mainland was due to poor mangroves stands due to poor environmental and edaphic conditions accelerated by overexploitation due to easy accessibility. Donato *et al.,* (2012), observed that a loss of 1% of mangrove C stocks from land use change could approximately double the GHGs emissions from these ecosystems, thus the ever-increasing populations adjacent to these creeks means increased pressures translating to increased emissions and consequently accelerated effects of climate change.

Available evidence (Lovelock *et al.,* 2011; Donato *et al.,* 2012) suggests that when mangroves and other tropical wetlands are cleared a significant portion of soil organic matter is oxidized, likely affecting even deep layers and leading to relatively large C emissions. A small disturbance releases a lot of C for instance initial published estimates for C released from Indo-pacific mangroves with land use change ranged from approximately 400 – 1400 Mg CO_2

equivalents per hectare cleared, depending on severity of disturbance (Donato *et al.,* 2011). Worldwide, forests are estimated to release 80 Pg (petagrams) of CO_2 into the atmosphere annually (Kirui *et al.,* 2012) part of this (363.67 t/ha) is from mangroves. According to Donato *et al.,* (2012), deforestation generates approximately 8-20% of the anthropogenic C emissions globally hence need for practical tool for supporting sustainable forest management in order to reduce this impact.

5.7Comparisons between Tudor and Mwache creeks

In both creeks, there were variations and significant disparity in all the parameters measured between the highly degraded and relatively less degraded sites. On structural characteristics, biomass SOM, percentage SOC concentration and carbon;Mwache was better than Tudor due to less pressure. The bulk density was high in Tudor than Mwache due to increased degradation in Tudor from intense pressure exerted by the ever-increasing population in the neighbourhood informal settlement.Peri-urban mangroves are under anthropogenic pressures and stress due to overexploitation and overharvesting for domestic fuel wood and industrial energy, human encroachment for housing and pollution (Taylor *et al.,* 2003; Omar *et al.,* 2009). Generally, based on the discussed resuts,Tudor creek is more degraded than Mwache.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Estimating C emissions in coastal areas is of significant importance in mitigating climate change. Deforestation contributes about 20% of carbon emissions and with mangroves being critical C sinks, then their rapid degradation rates is of great concern. Studies, which experimentally determine differential emissions, are globally limited and completely non-extent in Kenya. This was the focus of the study: comparing between highly degraded and less degraded areas. Highly degraded sites had much higher emissions than less degraded sites as discussed. Overall, Tudor Creek had higher emission rates due to unprecedentedly high deforestation rates of 5.1%, way above the global mean of 1-2% pa. This study revealed high degradation as shown in the reduced C stocks hence high emissions. The unprecedented high degradation rates, which exceed by far the national, mean and probably the global mean shows that the mangroves are highly threatened due to the discussed pressures. For instance, the carbon emission in Tudor creek was estimated at 91.32t/ha/yr, which translates to 335.13t/ha/yr CO_2 equivalents.

6.2 Recommendation

Although many studies have been carried out on C stocks at national or global levels, no previous study had been conducted on C emissions from these sites. The current study constricted C emissions from mangrove on specific impacted zones, making it easier for the forest managers and the conservationists to fund and allocate resources founded on findings of the study on the rate of emissions. This provides a baseline onthe sites and thedominant species for restoration activities especially the highly degraded sites based on their suitability to colonise degraded sites and capacity to withstand harsh environmental, climatic, and edaphic factors. There is need to strengthen the governance regimes throughenforcement and compliance and more capacity in mandated institutions e.g. NEMA and KFS; community involvement e.g. CFAs to curb illegal activities (logging, and distilleries). Advocating for ecosystem approach, which integrates upland land-use, practices to downstream mangrove conservation. Management strategies suggested includes initiating restoration activities where natural regeneration has failed, providing residents with alternative and cheap sources of energy and building materials and enforcing a complete moratorium on wood extraction will allow recovery. Achievement will highly depend on the management planning e.g. current drive to develop a mangrove management plan the first in the country to guide in mangrove forest management.

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