International Journal of Environmental Science and Toxicology Research (ISSN: 2408-7262) Vol. 6(1) pp. 1-11, February, 2018
Available online http://www.internationalinventjournals.org/journals/IJESTR

Full Length Research Paper

Differential Mangroves Degradation Rates: Case of Tudor and Mwache Creeks, Mombasa, Kenya

Nyamao, W. N. and Ogendi, G. M.

Department of Environmental Science, Faculty of Environment and Resources Development, Egerton University, P.O. Box 536, Njoro, Kenya

Received 15 December, 2017; Accepted 2 February, 2018

Limited economic opportunities and legislations in the Kenyan coast led to widespread mangroves degradation. This was despite the recognition that mangroves capture about 3-5 times more carbon per unit area than any vegetated ecosystem. Globally, studies assessing differential degradation rates are limited and rarely existent in Kenyan scenario. This study sought to establish the disparities in degradation rates along the Kenyan coastline by assessing two highly impacted creeks: Tudor and Mwache in a peri-urban setting as a case study. The total ecosystem carbon stock was estimated at 131.64±57.3C t ha^{-1} comprising of 66.22±6.3t/ha AGC, 20.7±0.2t ha^{-1} BGC and 44.34±2.05C t ha^{-1} SOC and 293.35±47.2t ha^{-1} comprising of 87.35±38.66t ha^{-1} AGC; 30.28±13.22t ha^{-1} BGC and 175.71±46.72C t ha^{-1} from the sediments for Tudor and Mwache creek respectively. The results show that Tudor creek is more degraded than Mwache creek. There is a need to strengthen the governance regimes through enforcement and compliance to address anthropogenic pressures. Advocating for an ecosystem approach in mangrove conservation. Management strategies suggested initiating and providing residents with alternative and cheap sources of energy, building materials and enforcing a complete moratorium on wood extraction to allow recovery. Achievement will highly depend on the good will of the stakeholders.

Keywords: Differential degradation, Anthropogenic drivers, Mangrove degradation, Carbon stock.

INTRODUCTION

The location of the mangrove ecosystems along the intertidal gradient, makes them keystone coastal ecosystems. Although they constitute 68 species globally, they are constrained to 25°N and 25°S of equator covering an area of between 180,000 and 200,000 km^2 (Giri *et al.,* 2011). Mangroves are centers for rapid carbon cycling (Bouillon *et al.,* 2008) apart from offering critical ecological functions (Duke *et al.,* 2007) and ranking high among the carbon dense tropical forests due to the deep organic – rich soils (Donato *et al.,* 2011; Kauffman *et al.,* 2011). Of greater significance is that they sequester 14% of C in the oceans captured in the above ground and below ground vegetation components despite occupying less than 0.5% of the coastal ocean (Alongi, 2012). In the Kenya scenario, nine (9) mangrove species distributed in six families cover the coastline (Spalding *et al.,* 2010). Mangroves cover 3% of the forest area in Kenya or 1% of the country, making them a scarce but very valuable resource (Dahdouh-Guebas *et al.,* 2000). The mangroves of Mombasa creeks (Mwache and Tudor) have suffered the highest degradation rates of between 46 and 87% between 1992 and 2009 exceeding the global mean which stands at 1 – 2% (Bosire *et al.,* 2014).

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). Mangroves resilience to disturbances such as hurricanes, makes them self-sustaining, protective barrier for human populations living in the coastal zones (Alongi, 2009) (e.g. 2004 Tsunami, where vegetated areas were spared of the effects as compared with degraded areas (UNEP-WCMC, 2006). Mangrove ecosystem is a source of wood products – poles, timber, charcoal, non-wood products - salt, tannins, dyes (Nyamao *et al*., 2015) and provides fishing areas for local communities.

Despite the aforementioned importance, the rate of mangrove degradation globally stands at 1-2 % per year (Duke *et al.,* 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 poor or weak governance systems e.g. poor enforcement and compliance with 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. Infrastructural development, such as hotels, ports like Lamu Port-Southern Sudan-Ethiopia Transport (LAPSET) have greatly reduced the mangrove areas. The effects of climate change e.g. sea level rise, flooding, sedimentation affect 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 root system of the trees causing a massive die-back of the mangroves (Kitheka *et al.,* 2005).

The contribution to global carbon by forest degradation is about 20% and the continued degradation of the mangroves will significantly increase it as mangroves store about 3-5 times more C per unit area than all known forest ecosystems (IPCC, 2007). The UNEP-WCMC report (2006) noted that, 35% loss of the mangroves within the past two decades led to a large release of carbon exasperating global warming marvel. The paucity of studies to monitor differential degradation rates (Bouillon, 2011) are impacting on the specific mitigation strategies. Information on carbon storage in mangroves is widely available (Bouillon *et al.,* 2008; Donato *et al.,* 2011; Kauffman *et al.,* 2011; Laffoley, 2009). An estimate of the carbon storage and the assessment of the causes of degradation have been obtained globally (Donato *et al.,* 2011; Kauffman *et al.,* 2011; Nyamao *et al*., 2015), but the comparison of the degradation rates locally are less studied, hence the need for this study.

The high degradation rates documented for Mombasa mangroves and limited information on the differential degradation rates due to differences in locations and pressures provided an opportunity for this assessment. Past studies quantified total ecosystem C stocks (Adewole, 2012; Bosire *et al*., 2014; Mwihaki 2012), carbon emission from these creeks (Nyamao *et al*., 2015) but failed to specifically assess the differences in degradation rates between the two creeks which are facing different pressures. Assessing the differences in degradation out of alterations in pressures associated with natural and anthropogenic sources is paramount in giving a detailed analysis of mangroves degradation and anthropogenic activities and subsequently the differential impacts. The information will assist mangroves managers, conservationists and climate change experts in forecasting and predicting impacts between the creeks to address adverse environmental challenges. The study focused on the assessment of the differences in degradation rates by assessing the differences in C stocks in three carbon pools between the two creeks.

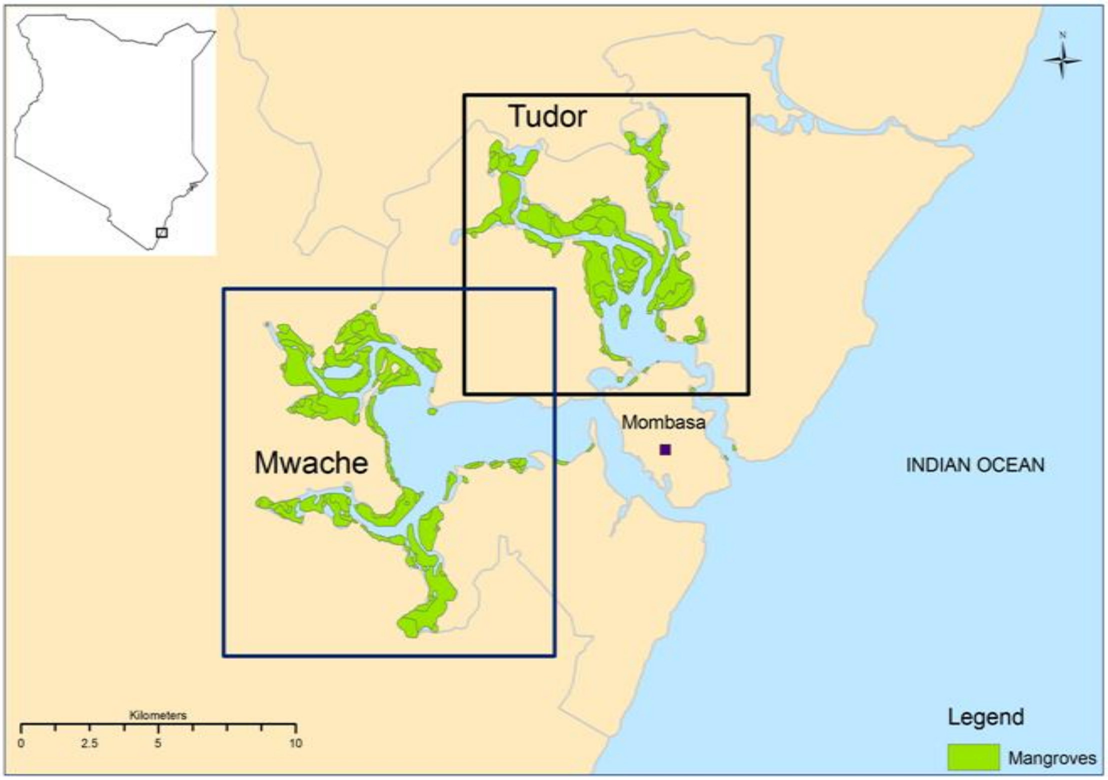
MATERIALS AND METHODS

Study area

This study was undertaken in Tudor and Mwache creeks in Mombasa. These two creeks were selected because they are adjacent to one another for comparisons, mangroves have faced threats due to high population pressures, poor land use practices upstream and indirect impacts of climate change (Bosire *et al.,* 2014; Nyamao *et al*., 2015), making 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 NW of Mombasa and extends some 10-15 km inland. 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 1). Within the creeks, mangrove forest extends over an area of 1,641 ha, mainly composed of *Rhizophora mucronata Lamk, Avicenia marina* (Forsk) and *Sonneratia alba* J. with no distinct zonation along the tidal gradient (Mohamed *et al.,* 2008).

Mwache Creek (4°3.01'S, 39.06°38.06'E), is located 20 km NW of Mombasa (Figure 1). 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 (Bosire *et al.,* 2014). The creek receives freshwater from seasonal Mwache River (Bosire *et al.,* 2006). 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).

The climate within Tudor, Mwache and Kenyan coast is under the influence of monsoon winds creating



(Source: Bosire *et al*., 2014)
Figure 1. Mangrove areas of Tudor and Mwache creeks

two rainy seasons. Heavy rains occur during the SE monsoon (March-May) and short rains during the NE monsoon (October-November). Mean annual rainfall is 900mm with a great inter annual variability. Dry spell occurs 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 main social economic activities of the inhabitants are; subsistence farming, fishing, wood harvesting, charcoal burning, which supports a population of about 50,000 persons (GOK, 2010). There is a poor infrastructural development in the areas, with low class housing and lack of enough social amenities.

Sampling procedure

In both creeks, transects perpendicular to the shore were laid in pre-selected sections of the mangrove forest, identified prior to field work using Google earth images based on vegetation density and stand structure. Data was collected using stratified random sampling for three carbon pools (above ground, below ground and soils). Carbon from understory, litter and deadwood pools were not considered in the study as their contribution to ecosystem carbon was negligible (Donato *et al.,* 2011). From the shoreline towards the mainland, 10 x 10m plots, approximately 100m apart were laid along intertidal transects. 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 7cm 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 the 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°C 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 a number of species, stand density, height and basal area.

$\mathrm{CI} = S * D * H * BA * 10-^{2}$ ……………………………Eq.1

Where: C.I – Complexity index; S – Number of species; D – Stand density; H – Mean height; BA – Basal area.

Biomass and Carbon estimation

The above ground biomass (AGB) and below ground biomass (BGB) were estimated from vegetation structure data and specific wood densities (ρ), (Bosire *et al.,* 2014) using the general allometric equations developed by Komiyama *et al.* (2005; 2008). 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.

$\mathrm{AGB} = 0.251 * \rho * \mathrm{DBH}^{2.46}$……………………………Eq. 2

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).

$AGC = AGB * 0.464$……………………………………Eq. 3

The BGB was determined using the general equations;

$BGB = 0.199 * \rho^{0.899} * DBH^{2.22}$……………………………………Eq. 4

C stocks in the BGB was calculated as a product of C concentration with a default value of 0.39.

$BGC = BGB * 0.39$………………………………………………Eq. 5

Bulk density (BD)

The sediment samples collected were placed on pre-weighed crucibles and oven-dried to a constant mass at 60°C and their weight recorded (Donato *et al*., 2011). To estimate soil BD (an indicator of soil compaction) the volume and the mass of oven-dried soil was used as illustrated below.

$\mathrm{Bulk\ Density\ (gcm-3)} = \{\mathrm{Mass\ of\ oven\ dried\ sample\ (g)} / \mathrm{Vol.\ of\ sample\ (cm3)}\}$…………………………………… Eq. 6

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°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.

$\mathrm{SOM\ Content} = \{(\mathrm{Initial\ weight} - \mathrm{Final\ weight}) / \mathrm{Initial\ weight\ (g)}\} * 100$……………………………………Eq. 7

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

$\mathrm{TOC\ (Mg\ Cha-1)} = \{\mathrm{Bulk\ density\ (gcm-3)} * \mathrm{Soil\ Depth\ Interval\ (cm)} * \%\mathrm{C}\}$…………………………Eq. 8

Data was analyzed using EXCEL and STATISTICA Version 8.0 to determine the relationship between drivers and mangrove degradation. To decipher any differences and relationships between the creeks, various statistical tools such as analysis of variance (ANOVA), regression analysis, correlations in addition to measures of central tendency and dispersion of 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, tables and boxplots.

RESULTS

Stand structure and Biomass distribution

In Mwache, four mangrove species were identified both in the adult and juvenile stages, whereas in Tudor they were five. *Rhizophora mucronata* was the dominant species and was encountered at all sites except at the island, where *Sonneratia alba* dominated. Tudor creek mangroves had a low basal area, low mean height, low stem density and hence a low complexity index as compared to Mwache. Tudor creek had the least mean structural characteristics and higher stump density (Table 1). Tukeys' test showed a significant difference in height (p=0.0462), basal area (p=0.056) amongst all the sites between Mwache and Tudor creek. 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±0.7cm^{2}), while the least was at Husein (9.87±0.1cm^{2}).

The mean live biomass in Tudor creek was

Table 1. Structural characteristics (Mean±SE) of mangroves at Tudor and Mwache creeks

Parameter	**Tudor creek**				**Mwache creek**			
Sites / C	Husein	Maunguja	Mikindani	**Mean**	Maweni	Mkupe	Island	**Mean**
Species	3	3	3	**3**	2	3	2	**2**
Ht (m)	2.55±0.3	2.59±0.19	3.03±0.3	**2.73±0.2**	4.56±0.2	4.61±0.7	5.41±0.1	**4.86±0.3**
DBH (cm)	3.54±0.3	3.94±0.07	5.30±0.9	**4.26±0.5**	6.05±0.3	6.58±1.0	9.12±0.4	**7.25±0.9**
BA (cm^2)	9.87±0.1	12.2±0.00	22.1±0.7	**14.3±0.2**	28.8±0.1	33.9±0.8	65.42±0.1	**41.3±0.7**
Stem D.	2533±261	3325±311	1925±212	**2594**±291	2310±211	2520±261	2633±272	**2487**±251
C.I	1.91	3.15	3.87	**3.04**	6.07	11.8	18.64	**9.98**
Stump/ha	37±17.9	16±3.94	39±19.5	**30.7±7.4**	15±1.27	10.0±0.58	8.67±2.4	**11.2±1.9**

estimated at 197.2±41 tha^{-1}, from AGB of 144.1±31 tha^{-1} and BGB of 53.0±9.7 tha^{-1}. Tudor creek biomass showed a significant difference (Tukeys' test) in AGB amongst the sites (p=0.004). Mwache creek mangroves recorded a mean biomass of 265.9±31 t ha^{-1}, from AGB of 188.3±20 t ha^{-1} and BGB of 77.7±10 t ha^{-1} (Table 2).

Bulk density

The mean bulk density (BD) 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 BD among the different sites along the depth profile (p=0.035). From the shore to the mainland along transects, there was a significant difference in BD (p=0.042) with the BD being high towards the mainland. The mean BD 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 BD 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). From the shore to the main land along transects, there was no significant difference in BD (P=0.051) (Figure 2).

Soil organic matter (SOM)

The percentage SOM in the mangroves of Mwache creek was 4.39±0.01%, ranging from 4.33±0.1% at Mkupe to 4.43±0.2% of the Island. 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 in the mangroves of Tudor creek was 7.06±0.4% ranging from 6.36±0.26% at Maunguja to 7.72±1.3% at Mikindani. There was a significant difference in percentage SOM within the creek (p=0.002). There was variation in percentage SOM in the deeper profile amongst the sites (Table 3) with a significant difference (p=0.03).

Organic carbon concentration

In Tudor creek the carbon (C) concentration ranged from 6.73±0.45% (Mikindani) 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 3). 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).

Vegetation Carbon pools

Tudor creek mangroves had a mean carbon of 87.0±18.3 tha^{-1}comprising of 66.3±14.6 t ha^{-1} AGC and BGC of 20.7±3.77 t ha^{-1}. The mean carbon in the mangroves of Mwache creek was estimated at 117.6±14C t ha^{-1} comprising of 87.4±9.67 t ha^{-1}AGC and BGC of 30.3±4.12 t ha^{-1}. There was a significant difference in AGC amongst all the sites (p=0.005). (Table 4).

Soil organic carbon

The soil organic C in the mangroves of Tudor creek was estimated at a mean of 44.34±2.05C t ha^{-1} (Figure 5). There was a significant difference (p=0.043) in the mean SOC amongst the sites. There was a steady increase in SOC along the depth profile 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=0.035). The SOC in the mangroves of Mwache was estimated at 175.71±46.72C t ha^{-1} (Figure 5). There was no significant difference (p=0.058) in the mean SOC amongst the sites. There was a steady

Table 2. Mangroves biomass distribution (Mean±SE) in Tudor and Mwache creeks during study

Parameter	**Tudor creek**				**Mwache creek**			
Sites / C	Husein	Maunguja	Mikindani	**Mean**	Maweni	Mkupe	Island	**Mean**
AGB (t/ha)	129.8±99	204.7±99	97.8±74	**144.1±31**	147±1.35	203.6±3.8	214±0.75	**188.3±20**
BGB (t/ha)	49.2±33	71.4±64	38.5±26	**53.0±9.7**	57.8±0.47	81.4±1.35	93.8±0.29	**77.7±10**
TOT B (t/ha)	179±99	276±99	136.4±99	**197.2±41**	204.8±36	285±102	307.9±64	**265.9±31**

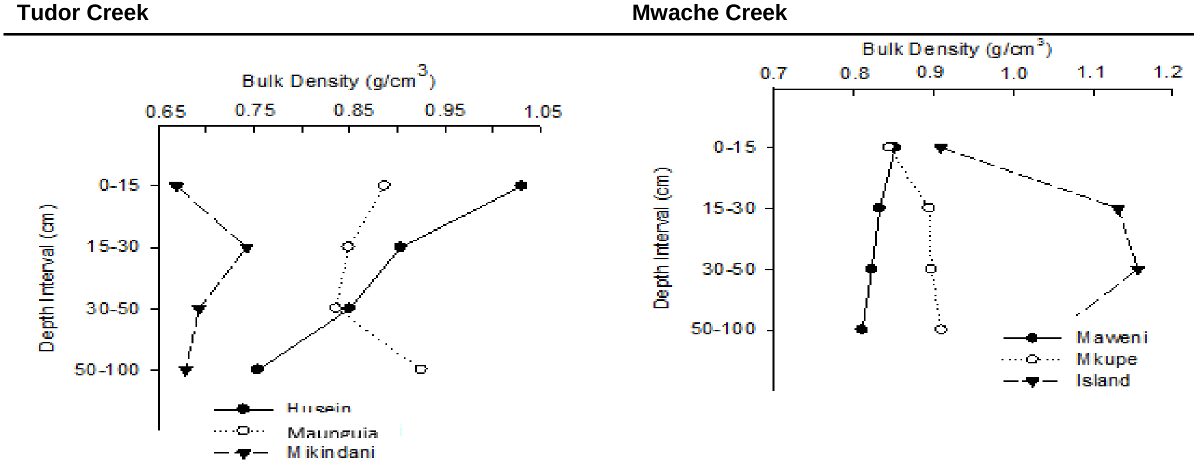


Figure 2. Soil bulk density along depth profiles in Tudor and Mwache creeks

Table 3. Mangroves SOM (Mean±SE) along depth profiles in Tudor and Mwache creeks

Parameter	**Tudor creek**				**Mwache creek**			
Site/Depth	Husein	Maunguja	Mikindani	**Mean**	Maweni	Mkupe	Island	**Mean**
0-15	6.76±1.3	5.17±0.7	7.54±1.4	**6.49±0.7**	4.41±0.1	4.17±0.1	4.17±0.1	**4.25±0.1**
15-30	7.00±1.6	7.08±0.5	8.62±2.7	**7.57±0.5**	4.23±0.1	4.75±0.3	4.63±0.1	**4.54±0.2**
30-50	7.16±1.8	7.76±0.8	7.74±0.7	**7.55±0.2**	4.52±0.1	4.44±0.3	4.45±0.1	**4.47±0.1**
50-100	7.49±1.1	5.45±1.1	6.97±0.5	**6.64±0.6**	4.37±0.1	3.96±0.4	4.48±0.2	**4.27±0.2**
Mean	7.10±1.4	6.36±0.3	7.72±1.3	**7.06±0.4**	4.38±0.1	4.33±0.1	4.43±0.1	**4.38±0.2**

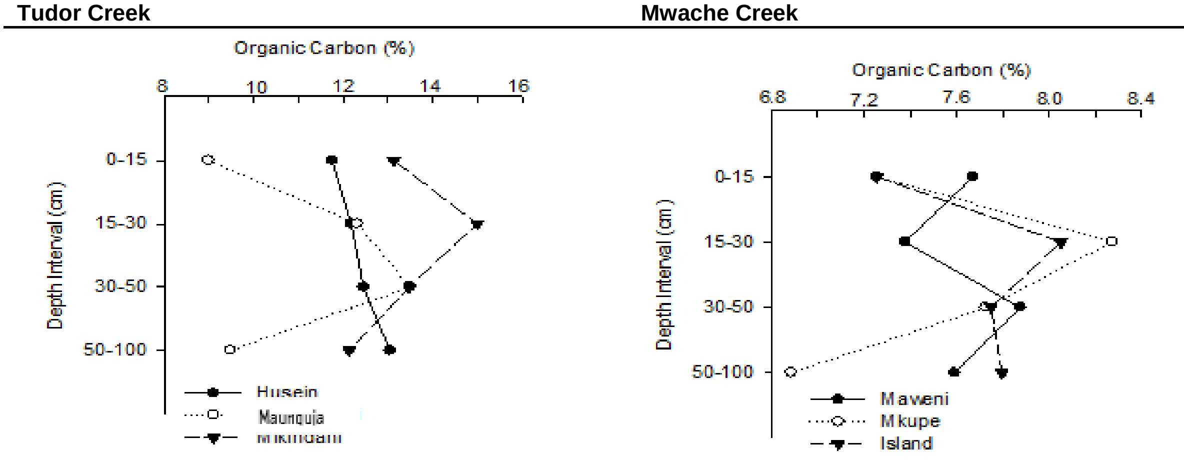


Figure 3. Organic carbon concentration distribution at Tudor and Mwache creeks during study

Table 4. Mangrove carbon distribution (Mean±SE)in Tudor and Mwache creeks during study

Parameter	**Tudor creek**				**Mwache creek**			
Sites/ C	Husein	Maunguja	Mikindani	**Mean**	Maweni	Mkupe	Island	**Mean**
AGC (t/ha)	59.7±47.1	94.2±88.7	44.9±34.2	**66.3±14.6**	68.2±12.6	94.5±35.4	99.4±20.8	**87.4±9.67**
BGC (t/ha)	19.2±13.2	27.8±25.2	15.1±10.2	**20.7±3.77**	22.5±3.73	31.7±10.3	36.6±7.69	**30.3±4.12**
TOT C (t/ha)	78.9±3.33	122±114	60.0±44.4	**87.0±18.3**	90.8±16.3	126.2±45	135.9±28	**117.6±14**

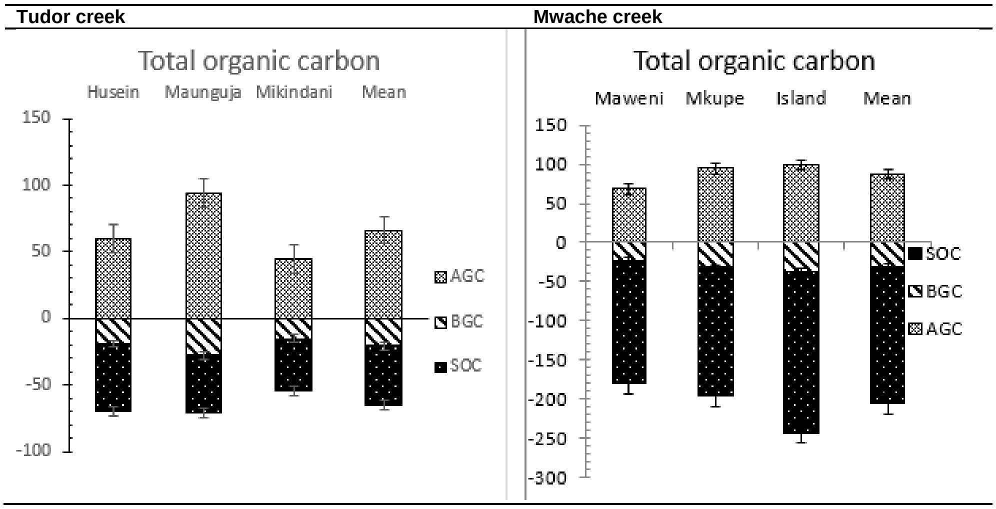


Figure 2. Ecosystem carbon pools (Mean±SE) at different sites in Tudor and Mwache creeks

increase in SOC along the depth profile with a significant difference (p=0.04).

Total organic carbon

The total ecosystem carbon stock in Tudor creek was estimated at 131.64±57.3C t ha^{-1}. This comprised of 66.22±6.3t/ha AGC, 20.7±0.2t ha^{-1} BGC and 44.34±2.05C t ha^{-1} SOC (Figure 5). The values show that the soil C contributed about 33.7% of the entire ecosystem C stock while AGC and BGC accounted for 50.5% and 15.8% respectively. The total ecosystem carbon stock in Mwache creek was estimated at 293.35±47.2t ha^{-1}. This comprised of 87.35±38.66t ha^{-1} AGC; 30.28±13.22t ha^{-1} BGC and 175.71±46.72C t ha^{-1} from the sediments (Figure 5). These values shows that the soil carbon contributed about 59% of the entire ecosystem C stocks while the AGC and BGC accounted for 29.7% and 10.3% respectively.

DISCUSSIONS

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 (Mohamed *et al.,* 2008). This was not the case in the Island where *Sonneratia alba* dominated due to preference to prolonged submergence and low salinity (Bosire *et al*., 2014). 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). Distribution and spatial patterns in natural mangrove stand are linked to variation in edaphic and environmental factors, predation by understory organisms and tolerance to disturbances (Bosire *et al.,* 2014; Mckee *et al.,* 2007).

The poor stand structure witnessed at the shores and towards the mainland could be due to ease accessibility (Nyamao *et al*., 2015). 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 limited growth parameters (Nyamao *et al*., 2015). Stand structure is a reliable indicator of forest development (Bosire *et al.,* 2014) and mangrove stand structure has a direct bearing on carbon stocks.

The pronounced human activities in the nearby farming areas have led to increased high sediment deposition evidenced by shallow sandy soils and large mudflats. Anthropogenic influences (indiscriminate and unregulated harvesting, raw domestic sewage discharge and enhanced siltation) have had cumulative effects on stand structure and regeneration of forest. According to Mohamed *et al*. (2008), anthropogenic drivers lead to characteristically high stump density and dominant crooked tree form which is the case in Tudor creek.

Total available biomass depends on the species, stand structure, and prevailing environmental conditions. In both creeks, the biomass was less 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. Additionally, 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 on landward edges (Kaino, 2012). This is because of increasing salinity along intertidal gradient, poor nutrients and dry ground (Nyamao *et al.,* 2015) accompanied with sedimentation. The AGB for Mwache (Table 2) 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 (Komiyama *et al.,* 2008).

Bulk density

The bulk density in Mwache varied greatly with a decline along depth profile up to one meter. This could be attributed to the 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.* (2011) in their study in Mexico. In Tudor creek, the bulk density showed no clear pattern along a 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 (Mwache creek), 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; Nyamao *et al*., 2015). It is expected that a well-structured soil would have a low bulk density, which generally increases with depth (Adewole, 2012).

Soil organic matter

The percentage SOM was higher on the shores, but reduced steadily towards the main land. This could be attributed to the 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.,* 2011). The availability and composition of percentage organic C buried in the mangrove 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. 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 situation 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.

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. According to Bosire *et al*., (2014), 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.

Carbon pools

On both creeks there was a steady increase in organic carbon along depth profile and may be attributed to compaction with time (Bosire *et al*., 2014; Nyamao *et al*., 2015). 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. The variations are due to different climatic conditions, management conditions, environmental stress, age, forest type and intensity of pressure (Kristensen *et al.,* 2008). This is in agreement with past studies that mangrove sediments are viable sites 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 (Bosire *et al*., 2014; Nyamao *et al*., 2015). This suggests that the persistent anthropogenic and natural disturbance reduce significantly the sequestration potential of the mangroves as exemplified by reduced C stocks estimates.

Comparisons between Tudor and Mwache creeks

In both creeks, there were variations and significant disparity in all the parameters measured between Tudor and Mwache creeks. On structural characteristics, biomass SOM, percentage SOC concentrations and carbon; Mwache was better than Tudor due to less pressure. The bulk density was higher 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 results, Tudor creek is more degraded than Mwache.

CONCLUSION AND RECOMMENDATION

Assessing differential degradation rates in coastal areas are of significant importance in mitigating climate change. Studies, which experimentally determine differential degradation, are globally limited and completely non-extent in Kenya. This was the focus of the study: comparing between two peri-urban creeks facing both natural and anthropogenic drivers. These two creeks were selected because they are adjacent to one another for comparisons, mangroves have faced threats due to high population pressures, poor land use practices upstream and indirect impacts of climate change. Overall, Tudor creek had higher degradation 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. 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.

The current study constricted degradation rates from mangrove on specific impacted zones, making it easier for the forest managers and the conservationists to fund and allocate resources founded on the findings of the study on the drivers and degradation rates. This provides a baseline on the sites and the dominant species for restoration activities. There is a need to strengthen the governance regimes to address anthropogenic pressures through mandated institutions and community involvement to initiate inclusive and comprehensive mangrove management. Advocating for ecosystem approach, which integrates upland land-use, practices to downstream mangrove conservation while strengthening the community sense of ownership. Management strategies suggested includes initiating total community awareness creation and inclusion of the economic and social aspects in the restoration activities, providing residents with alternative and cheap sources of energy and building materials to facilitate acceptance and enforcement of a moratorium on wood extraction to allow recovery. Achievement will highly depend on the good will of the stakeholders.

ACKNOWLEDGEMENTS

Gratitude to a number of people for their support and contribution in accomplishing this study. The vital support and dedication from supervisors for their tireless support, advice and zeal during the research work is greatly appreciated. Sincere gratitude also goes to all the KMFRI staff and technicians for their support and endurance, especially during field and laboratory work. Also, grateful to family members for their invaluable support, encouragement and prayers and to all that were not mentioned, thank you for your contribution at various stages of the academic journey; may the Almighty God bless you abundantly.

REFERENCES

Abuodha PAW, Kairo JG (2001). Human induced stresses on mangrove swamps along the Kenyan coast. K.M. F.R.I, Mombasa, Kenya. 458: 255 - 265, Netherlands

Adewole O (2012). Vegetation dynamics and carbon distribution in a heavily impacted peri-urban mangrove forest in Tudor creek, Kenya. Institute of International forestry and forest products, technische Universitat, Dresden.

Alongi DM (2009). The energetic of mangrove forests. NY: Springer Science and Business. Media BV 216p.

Alongi DM (2012). Carbon Sequestration in mangrove forests. Carbon management 3(3):313.

Aura S, Ngunjiri C, Maina J, Oloo P, Muthama J (2010). Development of a decision support tool for Kenya's coastal management. *Journal of Meteorology and Related Sciences.* KMS 10th Conference special issue: 39-47

Bosire JO (2010). Resilience of mangroves impacted by indirect effects of Global Climate Change: A Preliminary Assessment, *WIOMSA Marg II final report* 23p

Bosire JO, Bandeeira S, Rafael J (2012). Coastal climate change mitigation and adaptation through REDD+ carbon programs in mangroves in Mozambique: Plot in the Zambezi Delta. Determination of carbon stocks through localized allometric equations component. WWF 27p.

Bosire JO, Dahdouh-Guebas F, Kairo JG, Wartel S, Kazungu J, Koedam N (2006). Success rates of recruited trees species and their contribution to the structural dev. of reforested mangrove stands. *Marine Ecology Progress Series*, 325:85-91.

Bosire JO, Kaino JJ, Olagoke OA, Mwihaki LM, Ogendi GM, Kairo JG, Berger U, Macharia D (2014). Mangroves in peril: unprecedented degradation rates of peri-urban mangroves in Kenya.

Bouillon S (2011). Carbon cycle. Storage beneath mangroves. Vol. 4, Macmillan Pub. UK.

Bouillon S, Borges A, Castaneda ME, Diele K, Dittmar T, Duke N, Kristensen E, Lee S, Marchand C, Middleburg J, Rivera-Monroy V, Twilley R (2008). Mangrove production and carbon sinks: A revision of global budget estimates. Global Biogeochemical Cycles 22

Bouillon S, Middelburg J, Dehairs F, Borges A, Abril G, Flindt M, Ulomi S, Kristensen E (2007). Importance of intertidal sediment process and pore water exchange on the water column biogeochemistry in a pristine mangrove creek (RasDege, Tanzania). *Biogeosciences* 4: 311-322 GB 2013, doi: 1029/2007 GB003052

Ceron-Breton JG, Ceron-Breton RM, Rangel-Marron M, Muriel-Garcia M, Cordova-Quiroz AV, Estrella-Cahuich A (2011). Determination of carbon sequestration rate in soil of a mangrove forest in Campeche, Mexico. *International Journal of Energy and Environment* 5 (3): 328-336

Dahdouh-Guebas F, Mathenge C, Kairo JG, Koedam N (2000). Utilization of mangrove wood products around Mida Creek (Kenya) amongst subsistence and commercial users. *Economic Botany* 54.

Donato DC, Kauffman JB, Murdiyarso D, Kurnianto S, Stidham M, Kanninen M (2011). Mangroves among the most C rich forest in the tropics. *Nature Geosciences*, DOI:10.1038 /NGEO1123.

Duke NC, Meynecke JO, Dittmann S, Ellison AM, Anger K, Berger U, Cannicci S, Diele K, Ewel KC, Field CD, Koedam N, Lee SY, Marchand C, Nordhaus I, Dahdouh-Guebas F (2007). A world without mangroves? Science 317:41-42

Giri C, Ochieng E, Tieszen L, Zhu Z, Sing A, Loveland T, Masek J, Duke, N (2011). Status and distribution of mangrove forests of the world using earth observation satellite data. *Global Ecology and Biogeography* 20: 154-159.

Government of Kenya (2009-2010). Kenya population and housing census report. Govt press.

Inter-governmental Panel on Climate Change (2007). Climate Change: The physical basis. In Contribution of Working Group 1 to the Fourth Assessment Report of the IPCC. Cambridge, United Kingdom and New York, USA: Cambridge University Press

Kaino J (2012). Structure, biomass and cover change of a peri-urban mangrove ecosystem in Kenya: a case study of Mwache creek. Thesis submitted to Egerton University, pp. 33-46.

Kauffman J, Heider C, Cole T, Dwire KA, Donato DC (2011). Ecosystem C pools of Micronesian Mangrove Forests: Implications of land use and climate change. *Wetlands* 31:343-352. DOI 10.1007/s13157-011-0148-9

Kitheka J (2002). Hydrodynamic processes, transport and flux of sediments in the Mwache creek mangrove wetland in Kenya, University of Nairobi, Kenya.

Kitheka J, Obiero M, Nthenge P (2005). River discharge, sediment transport and exchange in the Tana Estuary, Kenya. Estuarine, Coastal Shelf Science 63: 455-468.

Kitheka J, Ongwenyi G, Mavuti K (2002). Dynamics of Suspended Sediment Exchange and Transport in a Degraded Mangrove Creek in Kenya, *Royal Swedish Academy of Sciences Ambio* Vol. 31 No. 7-8.

Komiyama A, Ong JE, Poungparn S (2008). Allometry, biomass and productivity of mangrove forests: A review. *Aquatic Botany*: 89,128-137.

Komiyama A, Poungparn S, Kato S (2005). Common allometric equations for estimating the tree weight of mangroves. *Journal of Tropical Ecology*21:471-477.

Kristensen E, Bouillon S, Dittmar T, Marchand C (2008). Organic matter dynamics in mangrove ecosystems. *Aquatic Botany 89(2):201–219.*

Laffoley D, Grimsditch G (2009). The management of natural coastal carbon sinks. A short summary. IUCN. Gland, Switzerland G. (Eds)

Lovelock C (2005). Variation in Mangrove Forest Structure and Sediment Characteristics in Bocas del Toro, Panama. Caribbean Journal of Science, Vol. 41, No. 3, 456-464, 2005

Mckee KL, Cahoon DR, Feller I (2007). Caribbean mangroves adjust to rising sea level through biotic controls on change in soil elevation. *Global Ecology and Biogeography*, 16: 545-556.

Mohamend MOS, Neukermans G, Kairo JG, Dahdouh-Guebas F, Koedam N (2008). Mangrove forests in a peri-urban setting: The case of Mombasa, Kenya. *Wetlands Ecology and management:* 17 (3): 243-255

Mwihaki ML (2012). Carbon Stocks of the mangrove forest in Mwache Creek Mombasa, Kenya. Thesis submitted to Egerton University, pp. 28-51.

Nyamao WN, Bosire JO, Ogendi GM, Kiplangat J, Mwihaki L (2015). Carbon emissions from degraded mangroves of Tudor and Mwache creeks, Mombasa, Kenya. *Journal of Island Ecology*, Volume 1: 18 - 28

Omar M, Neukermans G, Kairo JG, Dahdouh-Guebas F, Koedam K (2009). Mangrove forests in a peri-urban setting: the case of Mombasa (Kenya). *Wetland Ecology and Management* 17: 243-255.

Santos G, Ceron-Breton R, Ceron-Breton J, Sanchez J, Hernandez D, Muriel M, Chavez A (2011). Preliminary study of carbon storage rate in mangrove soils in Atasta Peninsula, Campeche, Mexico. *Recent Advances in Fluid Mechanics, Heat & Mass Transfer and Biology* 111-116.

Spalding M, Kainuma M, Collins L (Eds.) (2010). World Atlas of Mangroves. Earth scan, London.

Taylor M, Ravilious C, Green EP (2003). Mangroves of East Africa. UNEP-WCMC Biodiversity Series No. 13.

United Nations Environmental Programme-WCMC (2006). In the Front Line: Shoreline Protection and other Ecosystem Services from the mangroves and Coral Reefs. In: UNEP-WCMC 33pp, Cambridge, United Kingdom.

How to cite this article: NYAMAO WN, OGENDI, GM (2018). Differential Mangroves Degradation Rates: Case of Tudor and Mwache Creeks, Mombasa, Kenya. Int. J. Environ. Sci. Toxic. Res. Vol. 6(1): 1-11.