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Biophysical factors influencing the choice of nesting sites by the green turtle (*Chelonia mydas*) on the Kenyan coast

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Abstract

The green turtle (*Chelonia mydas*) is the most common sea turtle nesting along Kenya's coastline. Varying biophysical factors influence choice of nesting sites where eggs are laid. This study was conducted between February and November 2016 and was designed to establish the relationship between numbers of *C. mydas* nests on the beach and biophysical variables such as vegetation cover, organic matter content (OMC), beach width, and beach slope. Multiple regression analysis was employed to assess the factors that contribute to the number of *C. mydas* nests on a beach. This analysis did not allow prediction of the number of nests in a statistically significant way ($F_{(4, 26)} = 0.094$, $p > 0.05$, $R = 0.120$). However, there was a decrease in the number of nests with increased vegetation cover ($b = -0.013$), OMC ($b = -8.114$), beach width ($b = -0.089$) and slope of the beach ($b = -0.352$). Approximately 70% of nests occurred on beaches with medium and fine sand. Beaches with intense human activities were associated with high OMC which significantly affected the number of nests on the beach. It is therefore recommended that existing laws should be enforced to control beach development and human activities along the Kenyan coast to protect nest sites. Additionally, long term monitoring should be put in place to evaluate the impact of human disturbance on the favourable biophysical factors influencing the number of nests on a beach, as a management tool in the conservation of *C. mydas*.

Keywords: Green turtle; *Chelonia mydas*; nest sites; nesting choice; Kenyan coast; conservation

Introduction

Green turtles (*C. mydas*) tend to prefer to nest in areas that possess specific beach qualities such as gentle slope, moderate vegetation cover, absence of barriers and pollution, medium sized sand particle, darkness and minimum human disturbance (Mortimer, 1990). However, Kenyan beaches have been adversely affected by anthropogenic activities that have the potential to impact negatively on this critical habitat in life cycle of *C. mydas*. Additionally, there is inadequate information on nest site ecology on the Kenyan coast, leaving institutions mandated to manage the species without a proper baseline for making decisions to conserve and protect them.

Data to determine sea turtle population nesting trends of is not sufficient in Kenya (National Marine Fisheries Service and US Fish and Wildlife Service, 2007). Turtle

nesting, mortality, hatching and incidental catch is monitored at key sites along the Kenyan coast by government institutions, local Non-Governmental Organisations and Beach Management Units (BMUs - community groups registered by the Ministry of Fisheries). There is, however, inadequate information on *C. mydas* nesting on the coast of Kenya (Okemwa and Wamukota, 2006). The information on factors affecting turtle nesting is either inadequate or not harmonised, hampering conservation and management efforts (IUCN SSC, 1996). Demographic parameters are difficult to estimate owing to the long-term research required and the complexity of turtle life cycles. Animals that do not provide parental care have to ensure that a considerable number of their offspring survive to the next generation to keep the species viable, and natural selection favours individuals who make choices that enhance fitness of their offspring. Nest site selection can be

defined as the placement of eggs by females at sites that differ from random sites within a delimited area (Wilson, 1998). The nest site that a female chooses will determine the level of success of hatchling emergence. Understanding habitat features which determine successful nest site selection are important in conservation and management of a particular species.

Reproductive biology has been identified as one of the key global research priorities for sea turtles. Important information required for each species includes determining the factors that underpin nest site selection, nesting behaviour, primary sex ratios produced (how they vary within or among populations), and the factors that are important for sustained hatchling production (Hamann *et al.*, 2010). An assessment of the distribution and status of critical nesting habitats and their protection both current and anticipated threats is crucial to the conservation of turtles. This is because management decisions must include precise assessment of population size, including determination of whether populations are stable, increasing, or declining (Eckert *et al.*, 1999). The Marine Turtle Conservation Strategy and Action Plan for the Western Indian Ocean (IUCN SSC, 1996), which includes the Sodwana Declaration, tasked Kenya to identify nesting and foraging habitats so as to assess, monitor, and regulate fisheries impacts on turtles, as this information was lacking for the country. Other information gaps identified included inadequate data and information on population status and structure, and underestimation of nest numbers due to incomplete coverage of nesting beaches (Okemwa *et al.*, 2004). Kenya's sea turtle strategy also identified factors that make turtles vulnerable such as slow growth rates, susceptibility to predation and low recruitment rates from juvenile to adult life stages (Kenya Wildlife Service, 2010). The objectives of this study were to identify and geo-reference nest sites, characterise biophysical factors influencing nest site choice, and to recommend management interventions to conserve and protect nest sites of *C. mydas* on the Kenyan coast.

Materials and methods

Sampling areas

The green turtle nesting site investigation was carried out along the Kenyan coast (Fig. 1) which is approximately 600 km long, stretching from 1° 42' S to 4° 40' S, bordering Somalia in the north and Tanzania in the south (UNEP, 1998). This study was conducted in the coastal counties of Kwale, Mombasa, Kilifi and Lamu from February to November 2016. Nesting data for

the period from 2014 to 2016 was used to calculate the number of nests placed by *C. mydas* along the Kenyan coast. This data was obtained from various institutions and organisations engaged in turtle conservation such as Kenya Wildlife Service (KWS) for the Malindi and Watamu area, World Wide Fund for Nature (WWF) for the Lamu area, Baobab Trust (Kilifi and Mombasa areas), and BMUs (Kwale area). The data collected included number of nests, number of eggs laid, and number of hatchlings per nest site. The number of nests was obtained by recording the nests during regular patrols on the beach. The number of eggs laid was established by counting the number of eggs shells in nests after hatching. Biophysical factors investigated were vegetation cover, soil texture, OMC, width of the beach and slope of the beach. A total of 31 turtle nesting areas were investigated using a purposive sampling technique. The data was collected during low tide to allow for proper measurements of the beach variables at the nest sites. The beaches on which biophysical factors were investigated were classified as either occurring within or outside protected areas, vegetated or not, beaches with barriers to the sea, or open beaches, and those with open access or under cliffs.

Sampling Methods

Vegetation cover

Three quadrats measuring 1m by 1m were randomly established to determine the percentage of herbaceous foreshore vegetation cover at a nest site. The percentage vegetation cover was determined by a perpendicularly projected outline of the vegetation in the quadrat. For ease of estimation, the quadrat was divided into four equal quarters and the percentage vegetation cover was determined by addition of the estimated percentage vegetation cover in all the four quarters of the quadrat. Plants encountered in each quadrat were identified to species level (Abuodha *et al.*, 2003).

Organic matter content (OMC)

The Weight Loss on Ignition method (Agvise Laboratories, 2017) was used to determine the OMC of beach sand. Each of the soil samples was placed in the oven in aluminium foil to dry at 70°C for 72 hours. The sample was thereafter homogenised and three 5 g replicate sub-samples (Balance model Citizen, top loading analytical balance 0.1 mg) were put in a furnace of 450°C for 6 hours. The difference between the initial weight of the sample and final weight of the burnt sample represented the OMC. At 450°C the OMC was converted to carbon dioxide. The three replicates gave a mean for the OMC.

Soil texture

Three sets of soil samples were collected randomly from the nest site surface and at a depth of 50 cm. The three pairs of collected samples were sealed in

0.063 mm and 0.038 mm. The retained sample from each sieve was placed in a petri dish of known weight and weighed. The weight passing through each sieve was then converted into percentages of the total weight.

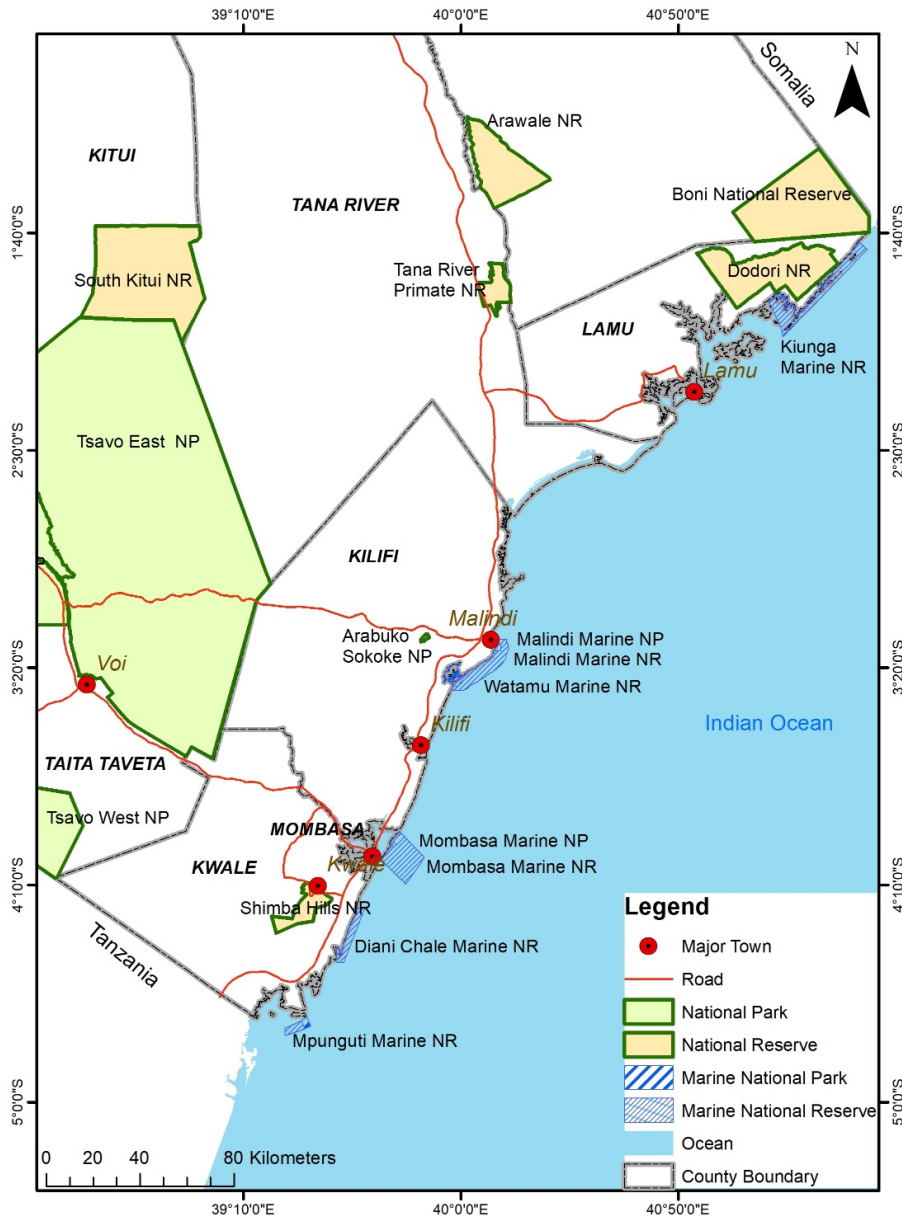


Figure 1. Kenyan coastline showing administrative boundaries and protected areas. (Source: KWS)

a polythene bag and taken to the Kenya Marine and Fisheries Research Institute (KMFRI) laboratory. The sieve method was used to determine soil texture (Gee and Bauder, 1986). Each sample was dried at 70°C for 72 hours. A sample of 100 g was placed on a shaker (Eijkelkamp) for 10 minutes with sieves of 1.60 mm, 1.00 mm, 0.710 mm, 0.500 mm, 0.250 mm, 0.125 mm,

Width of the beach

The distance from the fringing vegetation on the beach to the low water mark was measured using a meter rule (Varela-Acevedo *et al.*, 2009) with the sampled nest site as a reference point. Two measurements of beach width were taken (in metres) to get an average estimate of the width.

Slope of the beach

The slope of the beach was measured from the sampled nesting site point to the low water mark. The Emery survey method (Emery, 1961) was used as shown in Fig. 2. This approach had the advantage of being inexpensive and the light equipment could easily be carried across various beaches. Using the data from the beach profiles recorded from the field, cumulative vertical elevation (y-axis) as a function of cumulative horizontal position (x-axis) was plotted revealing the actual beach profile. Slope was calculated by dividing the difference in elevation between any two adjacent points by the difference in horizontal distance between those two points. The elevation in degrees was calculated from cumulated distance against cumulated elevation using the formula below.

$$\tan \phi = \frac{\text{cumulated elevation}}{\text{cumulated distance}}$$

thus, $\phi = \tan^{-1}(\text{cumulated elevation} / \text{cumulated distance})$

Data analyses

Spatial data analyses were conducted using Arc-GIS 10 to map the distribution of *C. mydas* nest sites. A Garmin GPSMAP 64s was used to record the UTM coordinates of the nest sites during field surveys. The nest site coordinates were recorded on the entire coast from Funzi Island in the south (Kwale County) to Mwongo Sherriff in the north (Lamu County). Correlation was used to find the relationship of number of observed nests with biophysical factors. Pearson Chi-Square was performed to determine the association between conservation status of nesting areas and classification of nesting areas by beach type. Multiple Regression analysis was performed to identify the biophysical factors

potentially influencing the number of nests recorded in 2016. The data were analysed at a confidence level of 95%, or $\alpha = 0.05$ using SPSS 23.0.

Results

Identification and geo-referencing of *C. mydas* nest sites

Coordinates collected by GPS showed the distribution of *C. mydas* nest sites along the Kenyan coast. Nesting sites in Lamu County had the highest number of nests per annum, while those in Mombasa had the lowest. Kilifi and Kwale had intermediate numbers of nests. In 2016 most turtle nesting occurred in areas which were not protected. Overall, areas within MPAs had fewer nests (42%) than those outside protected areas (58%) as shown by Fig. 3 and 4. All the nesting areas in Kwale County were outside protected areas because Kisite-Mpunguti MPA (Kwale County) has rocky beaches which were not suitable for *C. mydas* nesting. In Mombasa County, English Point and Nyali South were within the Mombasa MPA, and nesting was previously reported to occur at these locations but has decreased in the recent past. A large proportion of nest sites were outside MPAs in Kilifi County, and those within MPAs were found in tourist areas (Watamu Turtle Bay and Watamu Garoda Resort, within Watamu MPA). Malindi nest sites were all found in the Malindi MPA, and in Lamu County over 60% of nests were found within Kiunga Marine Reserve.

Types of beaches sampled

Nesting sites sampled were classified as those with barriers, open beaches, those under cliffs and those vegetated, as shown in Fig. 5. Nesting beaches with barriers constituted 12.9% (4 counts), open beaches 58.1% (18 counts), beaches under cliffs 3.2% (1 count) and those with vegetated beaches 25.8% (8 counts). In 2016 (Fig. 6)

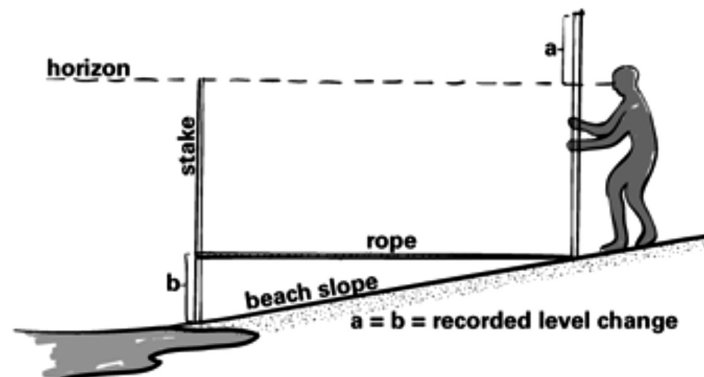


Figure 2. Emery Survey Method. (Source: Florida Centre for Instructional Technology, 2005)

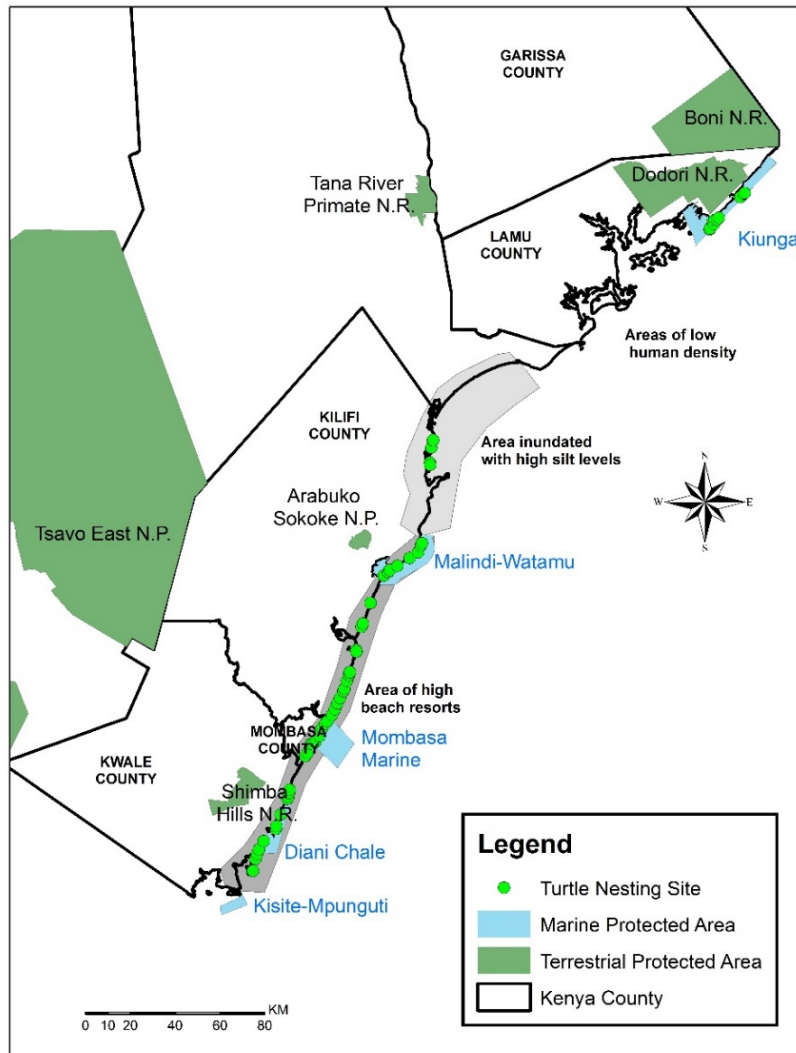


Figure 3. Nesting areas of *C. mydas* along the Kenyan coast.

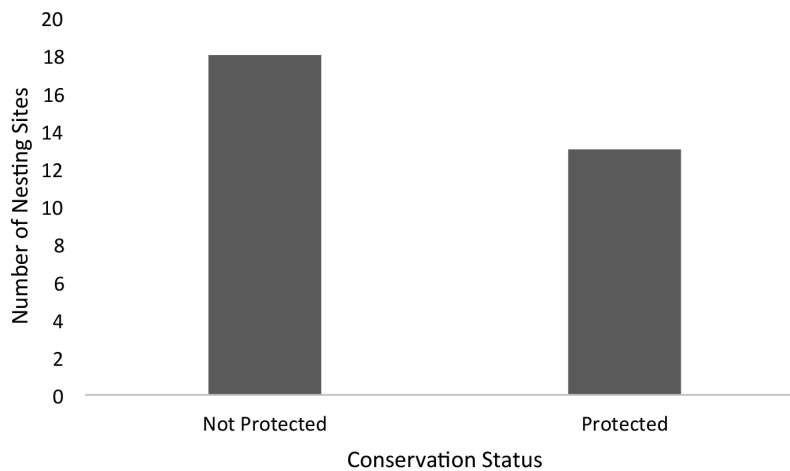


Figure 4. Conservation status of areas in which *C. mydas* nesting occurred in 2016.



Figure 5. Classification of sampled nesting beaches in 2016 along Kenyan coast.

open beaches had most *C. mydas* nests at 85% (196 nests), followed by vegetated areas at 12% (28 nests), and those with barriers at 2% (4 nests). The beaches with the least nests were under cliff at 1% (2 nests). As shown in Fig. 7, most of the open and vegetated beaches occurred in unprotected areas. There were two nesting sites with barriers in areas which were protected, while unprotected areas had no beaches under cliffs. Results from the Pearson Chi-Square test performed to establish the association between conservation status of nesting areas and classification of the beaches, indicate that there was no statistically significant association between protected and unprotected areas, because they had similar beach types ($\chi^2(3) = 1.625, p = 0.654 (p > 0.05)$). Cramer’s V tests show that the association between the variables was acceptable at a value of 0.229.

Vegetation cover at the nesting sites

The important herbaceous vegetation observed on Kenyan beaches was dominated by *Halopyrum mucronatum*, *Ipomoea pes-caprae* and *Scaevola plumieri*. These herbaceous plants grow above the high water mark, however they are inundated with water during spring tides. The average vegetation cover was 47% in all the sampled nesting areas. The nest sites with vegetation cover of less than 11% included Malindi MPA in Kilifi County, Leopard Beach in Kwale County and Kongowale in Lamu County. The observed number of nests at these sites was 0, 5 and 1 respectively in 2016. The nest sites with high vegetation cover of over 85% were Msambweni House, Seascape (Kwale County) and Aga Khan English Point (Mombasa County). The observed numbers of nests were 3, 1 and 5, respectively. Table 1 gives the number of nests in 2016 at

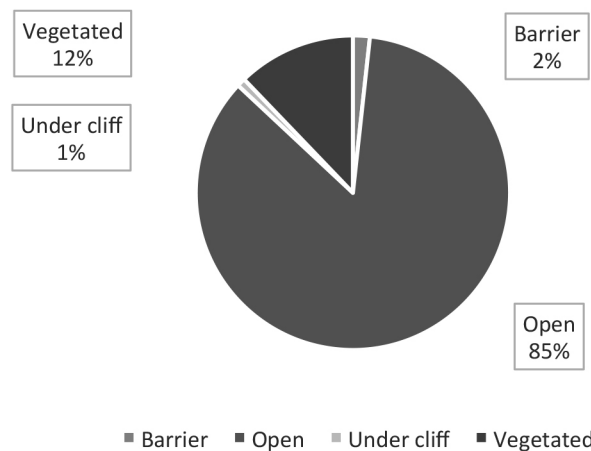


Figure 6. Percentage of number of nests found in 2016 per nest site classification.

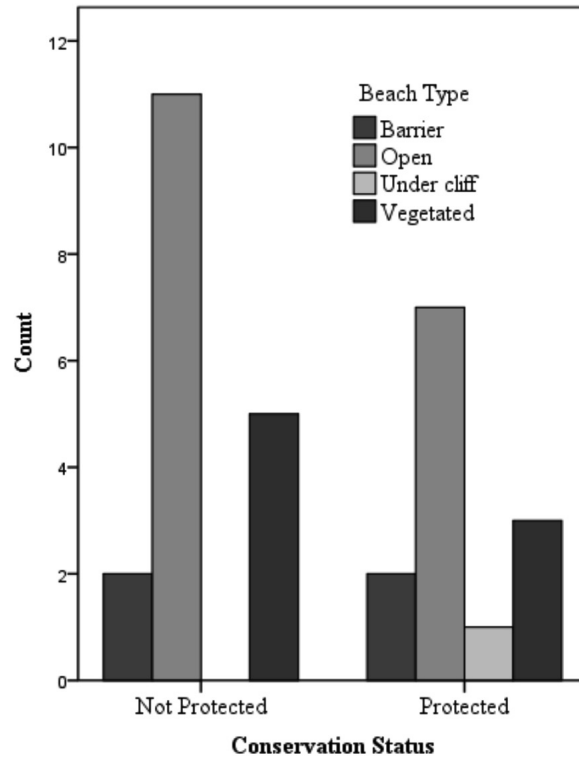


Figure 7. Comparison of conservation status and types of beaches in 2016.

various percentages of vegetation. Approximately 58% of nesting occurred within vegetation cover of 0-50%. Only 9% of nesting was observed to occur within vegetation cover of 76-100%. However, the Pearson product-moment correlation used to determine the relationship between vegetation cover and number of nests show that there was a weak, negative correlation between the two variables which was not statistically significant ($r = -0.055$, $n = 31$, $p = 0.767$ ($p > 0.05$)).

Organic matter content of nest site soils

Samples collected showed that areas with high OMC included Watamu Garoda Resort (Kilifi County), Mwanabule (Lamu County), Msambweni House and Seascape (Kwale County) with over 0.2 g of OMC. Nest sites with less than 0.01g of OMC were Kongo Mosque (Kwale County), Nyali South (Mombasa County) and

KSV (Lamu County). The average OMC in the sampled nesting areas was 0.11 g. Table 2 shows the amount of organic matter content in the soil at the nesting areas against number of nests observed along the Kenyan coast. 61.7% of nesting occurred in soils with 0.0500 - 0.0999 g of OMC. There were no observed nests in soils with 0.1500 - 0.1999 g OMC, while soils with 0.2000-0.2499 g of OMC had nesting of 7.4 %. The relationship between OMC in the soils and number of nests showed a weak, negative correlation between the variables which was not statistically significant ($r = -0.109$, $n = 31$, $p = 0.561$ ($p > 0.05$)).

Soil texture at nesting sites

All the soil samples were sandy without loam or clay content. Table 3 gives the average percentage of sand in the nesting areas. Most nests (69.81 %) occurred in

Table 1. Percentages of nests within vegetation cover along the beach.

Vegetation cover (%)	Number of observed nests	Percentage (%)
0 – 25	90	39
26 – 50	44	19
51 – 75	75	33
76 – 100	21	9

Table 2. Percentages of nests within ranges of soil organic matter content.

Organic Matter Content (g)	Number of observed nests	Percentage of nests (%)
0.0000 - 0.0499	57	24.78
0.0500 - 0.0999	142	61.73
0.1000 - 0.1499	14	6.09
0.1500 - 0.1999	0	0.00
0.2000 - 0.2499	17	7.39

Table 3. Percentages of soil texture classification at the nesting sites.

Very Course sand	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Silt
1.48 %	22 %	41.36 %	28.45 %	3.42 %	0.13 %

Table 4. Number of nests in relation to width of the beach.

Width of the Beach (m)	Number of observed nests	Percentage (%)
15 - 30	34	14.78
31 - 45	116	50.43
46 - 60	66	28.7
61 - 85	14	6.09

Table 5. Percentage of nests in relation to slope of the beach.

Slope of the Beach (°)	Number of observed nests	Percentage (%)
3.0-7.9	85	36.96
8.0-12.9	112	48.70
13.0-17.9	33	14.34

medium and fine sand, while very coarse sand had 1.48 %, coarse sand 22 %, very fine sand 3.42 %, and silt 0.13 % of observed nests. Kinondo nest site (Kwale County) had the highest amount of very coarse sand at 5.28 % at one observed nest, while the Bureni nest site (Kilifi County) had the highest amount of coarse sand at 75.63 % in 12 observed nests, KSV nest site (Lamu County) had 81.28 % of medium grained sand in 12 observed nests, and Nyali South nest site (Mombasa

County) had the highest amount of fine sand at 85.96 % with no observed nests in 2016, while Mwaeppe (Kwale County) had the highest amount of very fine sand at 31.37 % in two nests in 2016.

Width of the beach at the nesting sites

The widest beaches were Kiwayuu and Chandani (Lamu County), Nyali South (Mombasa County) and Mwaeppe (Kwale County) ranging between 61 and 85 m.

As shown in Table 4 these beaches had the least number of observed nests at 6.1 %. The narrowest beaches were Bureni in Kilifi County, and Massage Area and Kinondo in Kwale County. Highest nesting (79.1 %) was observed to occur within a beach width of 31 to 60 m. The average beach width was 44.4 m from the sampled nesting areas. There was a weak, negative Pearson's correlation which was not statistically significant ($r = -0.025$, $n = 31$, $p = 0.895$ ($p > 0.05$)), hence inconclusive evidence about the significance of the association between width of the beach and number of nests.

Slope of the beaches at the nesting sites

Most of the observed nests in 2016 had gentle slopes ranging between $8.0^\circ - 12.9^\circ$ (Table 5). These were Kitanga Kikuu, Mwanabule, Mongo Sherriff (Lamu County), and Mwanamia and Musumarini (Kilifi County). The average slope of nesting beaches was 9.44° with a higher number of nests (85.66 %) occurring on near flat to gentle slopes of $3.0 - 12.9^\circ$. Least nesting (14.34%) occurred on steep beaches of $13.0 - 17.9^\circ$. Pearson's correlation test established a weak, negative correlation between the variables which was not statistically significant ($r = -0.008$, $n = 31$, $p = 0.968$ ($p > 0.05$)).

Discussion

Identification and geo-referencing of *C. mydas* nest sites

Sea turtles have been known to nest along the Kenyan coast with over 90% consisting of *C. mydas* (Okemwa *et al.*, 2004). Green turtles have been documented to migrate over 2000 km between their feeding and nesting grounds (Read *et al.*, 2014). Lamu had a high numbers of nests in comparison with other parts of coastal Kenya. Long term studies from South Africa showed that MPAs are effective management tools in the conservation of loggerhead and leatherback sea turtles. The study however indicated that since future factors affecting nesting of sea turtles are stochastic, the presence of MPAs cannot effectively help to predict the status of future populations (Nel *et al.*, 2013). Sea turtle population have been observed to recover in protected areas globally, attributed to conservation efforts aimed at managing nesting areas and reduction of by-catch (Mazaris, *et al.* 2017). Tracking turtles with satellite tags has shown that *C. mydas* benefitted from protection offered by the Tortugas National Park, Florida, USA, with extended periods spent in the protected areas (Hart *et al.*, 2016). In Kenya, the MPAs are proportionally small in comparison to the whole length of the coast, perhaps explaining why most *C.*

mydas (58.1%) nest in unprotected areas. However, a high number of nests were observed to occur in Lamu within Kiunga Marine Reserve. The legal notices that established MPAs in Kenya are not clear on the conservation status of beaches within MPAs, making it difficult to enforce laws to protect nest sites in the protected areas.

Vegetation cover at the nesting sites

Xavier *et al.* (2006) reported that *C. mydas* showed a preference of 76 % for nesting on sand dunes or vegetation zones. Nesting areas with very low vegetation cover (<10 %) causes nest cavities to collapse, while very high vegetation cover (>40 %) affected *C. mydas* digging success because of increased compactness of the surface layer associated with root systems. Moderate vegetation (10 - 30 %) assists in sand accumulation and nest site stabilisation (Chen *et al.*, 2007). Madden *et al.* (2008) reported that there was decreased egg mortality in the upper beach due to increased proximity to vegetation. Clutches laid under large bushes and trees had higher hatching and emergence success than those in other habitats (Zarate *et al.*, 2013). Beaches without vegetation have an effect on thermal regimes of nests that influences incubation and resulting sex ratios (National Marine Fisheries Service and US Fish and Wildlife Service, 2007). Most of the nesting sites observed on the Kenyan coast were on sandy beaches with vegetation cover. The mean percentage vegetation cover was $46.9\% \pm 25.95$ SD.

Organic matter content of nest site soils

Organic matter builds soil structure improving soil drainage and infiltration of water and air into the soil. It also increases the ion exchange capacity of soil and provides a buffering effect on soil pH (Gachene and Kimaru, 2003). OMC is an important factor in nest selection because soils with high OMC contain water-stable aggregates that bind soil particles together and are resistant to being broken down by the impact of water (Gachene and Kimaru, 2003). High OMC also supports vegetation cover that is sometimes crucial in nest placement. A high percentage of vegetation cover however makes it more difficult for the sea turtle to dig and lay eggs (Chen *et al.*, 2007). Stancyk and Ross (1978) reported that beaches with high OMC were often found near to human settlements and activities. High OMC was observed in Msambweni House and Seascape (Kwale County), Watamu Garoda Resort (Kilifi County) and Mwanabule (Lamu County) which all had intensive human activities. Weslawski *et al.* (2000) observed that one of the main threats to sandy

beaches is eutrophication which leads to growth of invasive vegetation on the beach, affecting its ecology.

Soil texture

C. mydas dig in sandy beach soils to create cavities in which to lay eggs. Soil is made up of solid particles, water and air which are important in embryo development and determining the survival of the hatchlings. Soil texture determines soil workability, water-holding capacity, soil structure and nutrient retention (Gachene and Kimaru, 2003). *C. mydas* can nest in sites with a variety of soil particle sizes (Chen, *et al.*, 2007). Studies on Ascension Island show that the median number of trial nest holes dug per nesting emergence, and the mean particle diameter of the beach sands were positively correlated. Thus, turtles find it difficult to construct suitable nests in coarse and dry sand. The relationship between the average total survival of hatchlings and the sorting coefficients and mean particle diameters shows lowest survivorship in the most poorly sorted sand (Mortimer, 1990).

Width of the beach at the nesting sites

Narrow beaches are more vulnerable to the effects of climate change as sea level rise will wipe out possible nesting grounds of sea turtles (Fish *et al.*, 2005). Narrow beaches have high rates of erosion, especially if there are overhanging cliffs. Even on narrow beaches with minimal human activities, the number of nests will be low because of disturbance by wave action (Tsoukala *et al.*, 2015). The Magogo nest site in Lamu County had only two nests in 2016 despite being secluded with minimal human activities.

Slope of the beaches at the nesting sites

Studies in Mexico indicated that 65% of nesting occurred in two zones; one with a gradual slope and mean beach width of 38 m, and the other with a moderate beach slope with a beach width of 30 m (Zavaleta-Lizárraga and Morales-Mávil, 2013). In Florida, USA, Rizkalla and Savage (2011) showed that sea turtles prefer to nest in intermediate inclines. This was confirmed on the Kenyan coast where *C. mydas* showed a preference for gentle slopes with a mean of $9.44^\circ \pm 3.24$ SD, and a mean beach width of 44.40 m ± 16.93 SD. Wood and Bjorndal (2000) reported that the mean slope of the beach for loggerhead turtles was 9° . However, from the findings of this study, there was a weak negative correlation between slope and number of nests. The slope of the beaches in coastal Kenya are affected by winds associated with the south east monsoon (SEM) from December to March, and

the north east monsoon (NEM) from April to September. Historical data shows that nesting of sea turtles in Kenya was high during the months of March to July.

Conclusions

The largest number of the green turtle nests was observed along the coastline of Lamu County. Nests were most common on the Island of Mwongo Sheriff within Kiunga MPA. A dwindling number of nests were observed in Mombasa and Kilifi Counties due to anthropogenic factors in the beach areas. Kwale County had intermediate observations with some areas having stable numbers of nests. Green turtles preferred to nest in areas with vegetation cover of less than 50 %, and 61.7% of nests occurred in areas with 0.0500-0.0999 g of OMC. The highest number of nests occurred on beaches with widths of 31- 60 m, while the least number of nests were on steep beaches with an inclination of $13.0 - 17.9^\circ$. Most nests occurred in medium and fine sand (69.81 %). Due to the removal of native beach vegetation to develop beaches, invasive plants were observed on some beaches, which act as barriers to nesting turtles. The invasive species need to be continually managed (removed) to allow other suitable beach vegetation to grow.

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