NESTING ECOLOGY OF THE GREEN TURTLE (LINNAEUS, 1758)

IN COASTAL KENYA.

BY

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NRM/PGFI/05/10

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF SCIENCE IN FISHERIES AND AQUATIC SCIENCES (AQUATIC SCIENCES) OF THE SCHOOL OF NATURAL RESOURCES MANAGEMENT, DEPARTMENT OF FISHERIES AND AQUATIC SCIENCES, UNIVERSITY OF ELDORET, KENYA.

NOVEMBER, 2013

DECLARATION

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ABSTRACT

During the past several decades there has been a general global decline in sea turtle populations attributed either directly or indirectly to anthropogenic and climate change effects. Relatively little is known regarding the preferences turtles may have for some nesting beaches over others but the information is necessary for conservation of populations. The objective of this study was therefore to determine the nesting ecology of the green turtle, *Chelonia mydas*, in selected beaches in coastal Kenya. Nesting patterns and hatching success of *Chelonia mydas* were monitored in the year 2012 on nine beaches on the northern coast of Kenya. The number of nests deposited during the year, hatching success, and spatial nesting patterns were monitored in the beaches for twelve months during 2012. At the nesting beaches, samples of sand were analyzed for grain sizes, moisture content, pH and conductivity and the relationships between nest abundance, hatching success and these variables analyzed through linear regressions, multiple stepwise regression and CART analysis. Peak nesting occurred in March (25 nests) and October (26 nests) with nesting rates varying between beaches. Spatial variation was observed in nest densities with a range of 0.4 to 6.7 nests per km among the beaches. The mean clutch size did not vary significantly among sites (Kruskal-Walis: $\chi^2_{0.5, 8} = 13.57$; p = 0.09), so was the variation in mean clutch size between months pooled for all sites (Kruskal-Wallis: $\chi^2_{0.5, 11} = 13.38$; p=0.26). Results of a Kruskal-Wallis test did not show any significant difference in mean monthly hatching success among sites for the *in situ* clutches (Kruskal-Wallis: $\chi^2_{0.5, 11} = 17.86$; p = 0.09). The *in situ* incubated eggs had higher hatching rate than translocated ones (**U** = 547, p = <0.0001). The pH, clutch size, distance from high tide line (HTL) and moisture content at sites were identified as important variables in partitioning the variance in hatching success of the green turtle following CART analysis. However, results of stepwise multiple regression identified only clutch size as a significant predictor of hatching success (F = 4.93, p = 0.03). Conductivity and moisture content were identified as important predictors of whether nesting abundance would be low, medium or high at sites following a Classification Tree Analysis. Results of this study should provide useful information on the nesting ecology of the green turtle for modeling spatial variability and for management of this endangered species in the Kenyan coast.

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ANOVA	Analysis of Variance
BTW	Bureni Turtle Watch
CART	Classification and Regression Tree
GPS	Geographic Position System
HTL	High Tide Line
ND	Nesting Density
IUCN	International Union for the Conservation of Nature
NEM	North East Monsoon
PSA	Particle Size Analysis
TDS	Total Dissolved Solids
SEM	South East Monsoon
ST	Sand Temperature
SWOT	State of the World’s Sea Turtles
TCG	Turtle conservation Group
WIO	Western Indian Ocean

ACKNOWLEDGEMENT

I would like to thank the persons without whom this project would not have been possible: Professor Boaz Kaunda-Arara and Dr. Julius Manyala, for supervising this thesis. Fieldwork would not have been possible without the help of Baobab Trust, Bureni Turtle Watch and Mwanamia Turtle Conservation Group. I would also like to appreciate Dr. Rene Haller, from the Baobab Trust, for his support in providing the historical nesting dataset. Many thanks to the Kenya Marine Fisheries and Research Institute laboratory technicians for their useful comments and advice on sand analysis. I would also like to thank my family for their invaluable support and patience during the writing of this dissertation.

CHAPTER ONE

1.0 Introduction

The life cycle of sea turtles involves movements over great spatial scales between nesting, resting and foraging grounds presenting them with a number of threats during their life cycles (Musick and Limpus, 1996). Sea turtles are vulnerable and some are threatened with extinction hence they are included in the IUCN Red List (IUCN) as requiring more conservation effort. The extensive beach developments associated with coastlines have resulted to not only loss of nesting habitats but also to other factors that influence hatchling success such as; artificial lighting, beach compaction, noise pollution, and coastal defenses such as sea walls which have led to alteration of beach characteristics (Mortimer, 1995). These factors have an influence on temporal and spatial variability in nesting activity of the sea turtles.

Five species of sea turtles are found in Kenyan waters for purposes of nesting or foraging (Frazier, 1975). The nesting species which also forage in Kenyan waters are; the green turtle (*Chelonia mydas,* Linnaeus, 1758), hawksbill turtle (*Eretmochelys imbricata,* Linnaeus, 1766) and olive ridley (*Lepidochelys olivacea,* Eschscholtz, 1829). The foraging species include the loggerhead turtle (*Caretta caretta,* Linnaeus, 1758) and the leatherback turtle (*Dermochelys coriacea,* Vandelli, 1761). Sea turtles spend most of their adult lives in the sea but emerge onto beaches to lay eggs in nests which they excavate in the sand. As with many other oviparous animals, the position of the placement of a nest strongly influences the probability of offspring survival (Foley *et al*., 2006). Several abiotic factors such as; substrate type, porosity, temperature, moisture content salinity (Mortimer, 1990; Wood and Bjorndal, 2000; Ackerman, 1997; Bilinski *et al.*, 2001), slope of the beach, nest elevation (Horrocks and Scott, 1991; Foley *et al.*, 2006) rainfall and tidal inundation (Donlan *et al.*, 2004) have implication on nesting in turtles. After the emergence of turtle hatchlings, their survival is strongly related to the distance at which the nest is laid from the sea and distance from supra-littoral vegetation (Mrosovsky, 1983). Placement of nests close to the sea increases the likelihood of inundation and egg loss to wave erosion, whereas placement of nests further inland increases the likelihood of desiccation, hatchling misorientation, and predation on nesting females, eggs, and hatchlings (Bustard and Greenham, 1968; Fowler, 1979; Whitmore and Dutton, 1985; Spencer, 2002). Despite the unequivocal documentation of the effects of beach characteristics on nesting (Mortimer, 1990; Foley *et al.*, 2006), there have been few studies on factors affecting nesting activity in Kenya and most of the Western Indian Ocean (WIO) region. The relative importance of these factors may vary at different spatial and temporal scales.

The lack of reliable quantitative data on nesting ecology is the greatest weakness to management of sea turtles in general (Mortimer, 1990; Bourjea *et al.*, 2008), and despite availability of long-term monitoring programs, data on nesting ecology of sea turtles in the WIO region is limited to census of nests with little information on impacting factors and variability of nesting activity at different scales (Bourjea *et al.*, 2008). This study therefore aimed at generating information on the onshore factors affecting nesting activity of the green turtle, *Chelonia mydas* in coastal Kenya. The results of the study should be useful in determining conservation strategies for the green turtle populations.

1.1 Problem Statement and Justification of the study

During the past several decades there have been a general decline in sea turtle populations attributed either directly or indirectly to habitat destruction including development of beaches for human habitation (Ehrenfeld, 1982). The future of marine turtles is said to be precarious due to these anthropogenic pressures (Poloczanska *et al.*, 2009). Despite intensive research efforts focused on individual nesting beaches, relatively little is known regarding the preferences turtles may have for some beaches (Mortimer, 1990). In order to successfully design conservation management plans that will be effective in conserving extant populations of turtles, it is imperative to study nesting ecology of turtles, especially the spatio-temporal dynamics of nesting activity and to be able to characterize the nesting beaches. The green turtle is the commonest species in Kenya both at foraging and nesting grounds (Wamukota *et al.,* 2010). An aerial survey conducted by the Kenya Wildlife Service (KWS) in 1994 found that sea turtles are widely distributed along the coastline within the 20m isobaths in areas mainly associated with sea grasses and coral reefs, implying the presence of a significant foraging turtle population in Kenya (Wamukoya *et al.*, 1995). The specific beach characteristics that influence the emergence of these foraging populations are largely unknown. The results of this study will be useful in adding scientific information on the ecology of turtles in the WIO region and for managing turtle populations in Kenya.

1.2 Research Objectives

Overall objective

The overall objective of this study was to assess the nesting activity and characterize the nesting beaches of the green turtle, *Chelonia mydas*, in coastal Kenya for the purposes of conservation of this endangered species.

Specific objectives

The specific objectives of this study were:

1. To review historical trends in turtle nesting activity in coastal Kenya.
2. To examine the spatio-temporal variation in the green turtle nesting activities and hatching success in selected beaches in coastal Kenya.
3. To determine the influence of physical beach characteristics and environmental variables (sand grain size, pore water content, salinity, pH and sand temperature) on nesting activity and hatching success of green turtles on selected beaches in coastal Kenya.

1.3 Research Hypothesis

This study was guided by the following statistical hypotheses:

$Ho_{1:}$ There is no significant temporal change in the green turtle nesting activity at the selected beaches.

Ho_2: There is no significant difference in spatio-temporal nesting activity and hatching success of the green turtles among selected beaches in coastal Kenya.

Ho_3: Environmental and physical variables (e.g. sand texture, pore water content, salinity, pH and sand temperature) at the sampled sites have no significant effect on nesting and hatching success of the green turtles.

CHAPTER TWO

LITERATURE REVIEW

2.1 Nesting turtle composition and temporal trends in nesting

Five of the world sea turtle species that occur in the Western Indian Ocean (WIO), are all listed in the IUCN red list with the leatherback (*Dermochelys coriacea,* Vandelli, 1761) and Hawksbill (*Eretmochelys imbricate,* Linnaeus, 1766) being listed as critically endangered (IUCN). Both the green (*Chelonia mydas,* Linnaeus, 1758) and loggerhead (*Caretta caretta,* Linnaeus, 1758) turtles are endangered while the olive ridley (*Lepidochelys olivacea,* Eschscholtz, 1829) is listed as vulnerable. There has been a dramatic decline in global turtle populations with certain species, notably leatherback and hawksbill, witnessing population declines of almost 80% in recent decades (IUCN, 2004).

The green and hawksbill turtles are the most widely distributed, most numerous, and have been the most severely impacted by directed exploitation (Hughes, 1974a, b; Frazier, 1980, 1982). The loggerheads and leatherbacks used to be abundant along the South African waters, but less common in the rest of the WIO region, and have had little importance in commerce and directed exploitation (Hughes, 1974a, b). Relatively little has been documented about the distribution of olive ridley and is not considered much more than a vagrant species to the WIO region (Bourjea *et al*., 2008). Green turtles (Plate 1) have been observed to forage in the shallows of tropical sea waters (Seminoff *et al*. 2003), where food is abundant, whereas leatherbacks choose pelagic areas to forage (Hays *et al.*, 2004). The hawksbill feed mainly on sponges, green turtle feeds mainly on seagrasses and algae, while olive ridleys feed on benthic invertebrates, and loggerheads feeds on crustaceans (Meylan, 1988; Gardner *et al*., 2006; Talavera-Saenz *et al*., 2007).

Trends in sea turtle population sizes are most often determined by numbers of nesting females or numbers of nests deposited, giving estimates of population changes over time (Sato *et al*., 1997; Bjorndal *et al*., 1999; Balazs and Chaloupka, 2004). Green turtles have been shown to nest all year-round with a bi-modal peak in Aldabra which is a pattern typical of most green turtle rookeries in the western Indian Ocean (Rene & Roos, 1996). The Seychelles and Comoros have the largest green nesting rookeries in the region. With the exception of the Comoros, where the nesting population has increased by 180% to 5,000 since 1974, all other populations of green turtles in the region have declined over recent decades. In the Seychelles for example, there were believed to be between 11,000 – 13,000 turtles nesting annually on assumption and Aldabra islands at the turn of the twentieth century (Hornell, 1927); the present figure is around 3,500 – 4,500, a decline of 65% (Mortimer, 1988). In Madagascar, loggerhead turtles may still be represented by substantial nesting populations in the south-east of the country (Rakotonirina & Cooke, 1994) and the South African population has more than doubled since the 1960s when strong protective measures were introduced.

Plates 1: A green turtle returning to the sea after nesting at Bureni beach in coastal Kenya (Source: Maina, D. 2012)

2.2 Turtle nesting and hatching success

The life cycle of sea turtles follows the same general pattern in all the species (Miller, 1997). Males and females travel from foraging areas to mating areas which are believed to be at offshore reefs, during the mating season. The mating season for green turtles has been observed to be all year round. Adult males can breed every year, but females only breed every 3-4 years or so. A few weeks after mating, females migrate to shallow water inter-nesting grounds usually at lagoons near nesting beaches where they continue to forage. Nesting turtle emerge to lay several clutches of eggs at an interval of every two weeks on different beaches for a period lasting several months before leaving the nesting grounds (Miller, 1997). Several clutch sizes, defined as the number of eggs laid at once in a nest chamber, are laid. Sea turtle nests are typically placed at depths between 25-150 cm and nesting turtles are conceivably able to gauge the height of the sand platforms on prospective nesting beaches, generally rejecting those which are less than a certain height above water level (Speakman *et al.*, 1998).

Different nesting activities are observed during a nesting season ranging from turtle tracks, nest cavity and hatching. The female can exhibit a pseudo-nesting behavior where she makes false nest cavities near the actual nest to camouflage it and thereby reducing the risk of predation of the eggs (Swaminathan and John, 2011). The males, meanwhile, remain in the mating areas or go back to feeding grounds. Post nesting migration of females to foraging areas may span upto thousands of kilometres before the next mating season (Miller, 1997). With the exception of *L. olivacea*, sea turtles do not tend to reproduce annually (Abreu-Grobois and Plotkin, 2008). After approximately 60 days of incubation, new hatchlings emerge from the sand during the night or early morning, and crawl to the sea (Miller, 1997), where they are generally transported by major currents to their feeding grounds, where they remain until maturity. Green turtles and hawksbill turtles have been seen to share the same nesting area, but at different times during the nesting season (Bjorndal *et al*., 1985). This temporal and spatial variation in nesting habits reduces competition for nesting sites between sea turtle species.

2.3 Influence of physical and environmental factors on nesting activity and hatching success

Identification of the possible cues driving nest site selection has received considerable attention (Miller, 1997). Various species of sea turtles have been shown to have different beach preferences (Hays *et al*., 1995) due to the different physical and environmental factors at these beaches. Mortimer (1982) determined that green turtles at Ascension Island (South Atlantic Ocean), tend to emerge on beaches with an accessible offshore approach. Provancha and Ehrhart (1987) suggested that offshore characteristics of beaches provide cues, such as slope, that loggerhead turtles use to select a stretch of nesting beach. Hawksbill turtles in Barbados also seem to use slope as a cue for beach selection, tending to nest on those beaches with steep slopes and low wave energy (Horrocks and Scott, 1991). The geographical position of nesting beaches is therefore an important factor in nesting site selection and the important factors may vary between beaches.

The green turtle tends to nest on open energy oceanic beaches with nests characterized by a deep pit and a symmetrical crawl leading to and from the ocean while the hawksbill turtles prefer nesting in remote pocket beaches, hiding their nests under vegetation spending several hours breaking roots and digging in the sand searching for the perfect nesting site (Wamukota *et al.*, 2010). According to Mortimer (1982), leatherbacks prefer high energy beaches; hawksbills tend to prefer heavily vegetated, low profile beaches while green turtles nest in open beaches. Nesting preferences of the olive ridley turtle include beaches where a river or an estuary is present (Márquez, 1996).

Among the physical characteristics of beach that play important roles in nesting site selection are; beach geomorphology (Johannes and Rimmer, 1984), texture of beach sand (Mortimer, 1990; Kikukawa *et al.*, 1999; Yalcin *et al.,* 2007), pore water content, and vegetation coverage (Mortimer, 1990). The presence of vegetation appears to be a very important cue in nest site selection, prompting turtles to lay their eggs either in front of or behind the vegetation line, depending on the effects of the vegetation on the physical properties of the sand (Mortimer, 1990), and on the ease of orientation for the newly hatched turtles at emergence (Godfrey and Bareto, 1995).

In many oviparous reptiles such as sea turtles, environmental factors influence embryo survivorship (Horrocks and Scott, 1991; Burger, 1993; Resetarits, 1996), hatchling size (Packard and Packard, 1988), growth performance (Janzen, 1993), hatchling growth (Joanen *et al*., 1987; McKnight and Gutzke, 1993; Bobyn and Brooks, 1994), behavior of hatchling (Burger, 1991), and sex determination (Ewert *et al.*, 1991; Janzen and Paukstis, 1991; Spotila *et al*., 1994). For successful incubation of the cledoic eggs of sea turtles, the substrate must be well ventilated, with low salinity and high humidity. Temperature-dependent sex determination (TSD, also called environmental sex determination, or ESD) among sea turtles operates to produce female hatchlings at warm temperatures and males at cool. Excess temperatures above the optimum tends to kill the embryo. Hatching success is further influenced by predation, rainfall and tidal over wash.

2.4 Knowledge gap

Generally, there are few studies that provide useful insight to the character of sea turtle nesting trends and habitats in Kenya. The green turtle nesters are the most abundant in numbers along the Kenyan coast and there seems to be a clear seasonality trend for its nesting pattern (Wamukota *et al.,* 2010). A general peak in turtle nesting occurs between the months of April and September, with main peaks being in May and June (Okemwa *et al.,* 2004), however, the inter-annual variation of this pattern is not known neither is the spatial uniformity of the pattern known for sites in the WIO. Wamukota *et al.* (2010) examined the influence of physical characteristics of the beach (sand organic matter, beach vegetation cover and beach width), oceanographic processes and human influence on nesting site preferences. The effect of temperature, high tide line (HTL), predation and human pressure has been highlighted by Nzuki and Muasa (2005) in beaches on the south of Kenyan coastline. However there are no studies that have examined the effects of pH, moisture content, conductivity and sand texture on green turtle nesting preference in Kenya. Moreover, the spatio-temporal variability in nesting activity has not been studied in relation to the different beach characteristics in coastal Kenya but may be important as highlighted by Mortimer (1990) and Foley (2006). The results of this study will therefore fill the gaps on the ecology of this common turtle species in Kenya and the most of the WIO region.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

Sampling was done at nine beaches, including English point, Nyali, Jumba ruins, Kikambala, Kijipwa, Msumarini, Vipingo, Bureni and Mwanamia (Figure 1). All the beaches are located north of Mombasa (Appendix 1). All the sites are characterized by presence of beach vegetation, open beach and pockets of cliffs on which green turtles nest. The Kenyan coastline is about 640km long extending from 1°41'S to 4°30'S latitude and is characterized by sandy peninsulas, tidal estuaries, fringing reefs, mangrove forests, rocky shores as well as sea grass beds. The coast is further characterized by two distinct monsoon seasons; the northeast monsoon (NEM) which prevails between November and March and the southeast monsoon (SEM) prevailing between April and October (McClanahan, 1988). The NEM season is marked by weaker winds and higher temperatures while the SEM season is marked by lower temperatures and stronger winds (McClanahan, 1988). During the SEM season, the East African Coastal Current speeds are high causing a major downwelling along northern Tanzania and southern Kenya (Bell, 1972; McClanahan, 1988). Salinity of coastal waters vary with the monsoon season with lowest salinities occurring at the onset of the SEM when discharge, cloud cover and rainfall are high; highest salinities occur during NEM season when air temperatures and solar insolation are high and rainfall and discharge low (McClanahan, 1988).

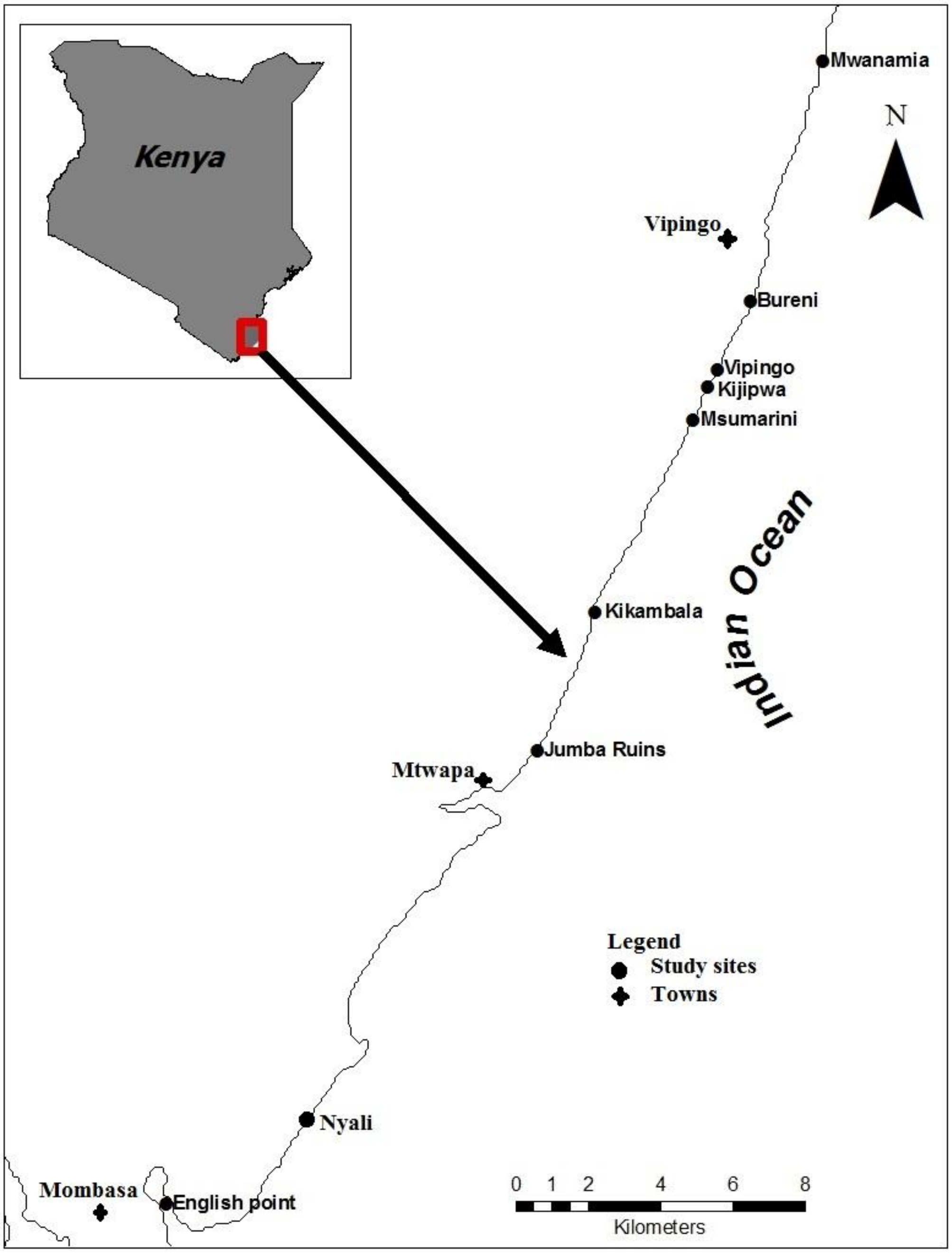

Figure 1: Map of a section of Kenyan coastline showing the studied beaches (Source: Author, 2012)

3.2 Study design

The green turtle population trends were examined using nest count data spanning twenty one years. The green turtle nest abundance, reproductive output and hatching success were determined at nine beaches over a twelve month period during the year 2012 and compared statistically between months and sites. The hatching success of the green turtle eggs was compared between the translocated and *in-situ* nature of incubation. The size morphology of the green turtle was estimated using track dimension at three sections of Bureni beach and comparison made between the beach sections. Environmental and physical characteristics such as distance of nest from HTL, pH, conductivity, moisture content and sand structure, of the sand substrate at Jumba ruins, Kikambala, Kijipwa, Msumarini, Vipingo, Bureni and Mwanamia beaches were examined and compared between the beaches. Relationships between HTL and number of nests, Hatching success and moisture content were examined and the important predictors of nesting activity and hatching success determined. Additionally, sand temperature at Bureni beach was recorded between the months of August 2012 to January 2013 and annual air temperatures for the year 2012 obtained to predict the annual sand temperatures at the beach which were in turn used to examine the relationship between nest abundance and temperature.

3.3 Field sampling

3.3.1. Nesting and hatching success

Sampling for spatial patterns of nesting and hatching success of the green turtle was concentrated at all the nine beaches located between -3.775^{o} S, 39.843 ^{o} E and -3.911 ^{o} S, 39.787 ^{o} E, on the northern Kenya coast (Fig 1). At the beaches data on number of nests laid, distance of nests from the high tide line using a measuring tape, number of hatched and unhatched eggs was recorded. The distance of the beaches was estimated by measuring the paths of beaches surveyed on Google earth. New nests were identified from fresh, soft sand thrown over the beach surface as a camouflage strategy by the nesting turtle and/or from the length difference between arrival and return tracks (Plate 2). The on-coming tracks for a turtle that had nested were longer than the out-going ones. The difference in track lengths often results from tidal wash during the extended nesting process (Hirth and Samson, 1987). Once examined, the tracks were erased by raking to avoid double counting. The located nest was verified for eggs by digging out the nest chamber and its position subsequently eyeballed in relation to important landmarks within the area. The distance of a nest location was measured from the high tide line (HTL) using a tape measure and position additionally marked using a handheld GPS (Garmin GPS 76). To identify the nesting species, the symmetry of the tracks was used (Prichard and Mortimer, 1999). Green turtle crawling flipper marks usually from a parallel pattern with a ridged track center, has a thin straight and well-defined tail-drag mark that is punctuated by tail-point marks, and regular markings from front flippers at the margins of the track (Plate 2).

Collaboration was sought with other turtle conservation groups (e.g. Baobab Trust and Mwanamia Turtle Conservation Group, TCG) to monitor English point, Nyali, Jumba ruins, Kikambala, Kijipwa, Msumarini, Vipingo and Mwanamia beaches for nesting activity which is defined as; anytime a gravid female sea turtle leaves the water to attempt nesting (SWOT Scientific Advisory Board, 2011). These groups relied on one trained community personnel per beach who conduct daily morning beach patrols to determine any sea turtle nesting activity. Therefore a total of nine community members were used. Data from the groups was collected on a weekly basis while additional but irregular patrols were jointly carried with the TCGs to monitor the activities to ensure uniformity in data collection.

In areas prone to inundation, the eggs were translocated to safer areas on the beach (herein after called translocated nests). Eggs that were at a high risk of poaching were translocated to a hatchery managed by the Baobab Trust.

The nesting rate (number of nests/month) was calculated as the number of successful nests per month while nesting density (number/km) at each beach was calculated as follows:

$$ND = Number\ of\ nesting\ pits/Length\ of\ surveyed\ beach$$

The hatching success which is the percentage of eggs that produced live hatchlings was determined by back tracking the seaward path of hatchlings (Mortimer, 1990) and digging the saucer shaped depression in the sand indicative of hatching activity below the surface. The content of all excavated nests (minimum 24 hrs after first emergence of the hatchlings) was categorized as; shells, live hatchlings, undeveloped, dead hatchlings, and unhatched, using existing protocols (Eckert *et al.*, 1999). Clutch size (number of eggs produced at one lay) was estimated by summing hatched and un-hatched eggs. Live hatchlings (Plate 4) were released to sea as a batch to minimize predation effects.

Plates 2: Green turtle hatchlings inside a nest chamber at Baobab hatchery, Serena beach in coastal Kenya (Source: Durcarme, F.)

At Bureni beach because of ease of accessibility and previously reported high nesting activity of green turtles, track dimensions were recorded. Night and morning patrols for new nests were conducted daily (as much as possible) with the help of assistants between January 2012 to January 2013. Depending on the tidal heights and timing, 2-3 hrs of night patrols were undertaken during high tides at Bureni beach. The track dimensions of nesting turtles were measured in a straight line from one outer flipper edge mark to the opposite outer flipper edge mark using a flexible tape measure in order to estimate the size of the turtle (Talbert *et al*, 1980) (Plate 2). The track measurements were taken at three beach sections of Bureni beach separated at an interval of about 0.14 km between zone 1 and 2, and 0.49 km between zone 2 and 3 (Plate 3).

Historical nesting data used in this study came from surveys by the Baobab Trust. Nest counts were done by the Trust at English point, Nyali, Jumba ruins, Kikambala, Kijipwa, Msumarini and Vipingo beaches from 1991 to 2012. Local community surveyors used visible track symmetry at nest sites to distinguish green turtle nests from nests of other sea turtles.

Plates 3: **Green turtle tracks observed during the surveys at Bureni beach. Marks indicate outer edges of the track. (Source: Nyale, C)**

Plates 4: **Map of the three beach sections (zones) at Bureni beach sampled for nesting activity (Source: NOAA)**

3.3.2 Environmental Parameters

Measurements of sand moisture content, grain sizes, conductivity and pH were taken at Bureni, Mwanamia, Vipingo, Msumarini, Kijipwa, Kikambala and English point beaches. Additionally monthly sand temperatures were taken at Bureni beach. Methods used to collect these environmental parameters are discussed in the following sections.

3.3.2.1 Moisture content and grain size measurements

Between three and nine sampling stations were located at each of the beaches (excluding English point and Nyali, Fig. 1) at an interval of 30m so as to span the nests and running parallel to the shoreline. The sampling stations were located as close to an existing nest as possible so as to approximate the environmental characteristics of the nest. Sand samples were taken from each station using a cylindrical plastic core at a depth of between 0.7 to 1m which is considered to be the average depth range of the green turtle nest chambers (Mortimer, 1992). Each core sample from the stations was stored in an air tight plastic vial wrapped with an aluminum foil and further enclosed in a plastic bag to minimize evaporation. Samples of sand each weighing 5g from each station were weighed wet in the laboratory and dried overnight in an oven at 70°C (Mortimer, 1992). The dry weight of each sample was then measured using a weighing machine. The difference between wet and dry weights (water content) for each sample was used to calculate the percentage moisture content of the sample (Bustard and Greenham, 1968) as:

$$Percentage\ (\%) moisture\ content = (water\ content/wet\ weight)\ X\ 100$$

Particle size of sand at beaches were analyzed from samples of sand weighing about 150 g and scooped from the beach surface at stations near nests and put in plastic bags. From these, a total of 65 sub-samples of approximately 100g, for all the beaches sampled, were used for Particle Size Analysis (PSA). The sub-samples were sieved, using sieves of six different mesh diameters corresponding to the Wentworth scale of sediment size classification as: 2mm (granules), 1mm (very coarse sand), 500µm (coarse sand), 250 µm (medium sand), 125 µm (fine sand), and 63 µm (very fine sand) (Trenhaile, 2005).

To facilitate the sieving process, sub-samples were dried overnight in an oven at 70°C. The total dry weight of each sub-sample was measured before sieving, and the fraction of the sediment retained in each mesh size was then weighed separately. The percentage of total weight for each grade of sediment size represented in the sample, was then calculated as:

$$Percentage\ of\ grain\ size\ category = \frac{(weight\ of\ the\ sand\ fraction\ retained\ in\ the\ mesh)}{(total\ weight\ of\ the\ sample)} \times 100$$

3.3.2.2 Conductivity, pH and Temperature measurements

The dried sand samples from each station that were used in the PSA analyses were remixed and 25g of the dried sand mixed with 25 ml of de-ionized water and the content mixed in an Eijkelkamp CE94 mechanized shaker. The mixture was then left to settle for around ten minutes after which the supernatant was decanted and used to determine both conductivity (as a measure of salinity) and pH measurements. Conductivity was measured using a TDS meter

(HANNA HI 8734), whose reading was converted to mmhos/cm. pH was measured using a pH meter.

The daily sand temperatures were monitored *in situ* at Bureni beach using a HOBO Pro v2 temperature logger. The logger was buried at about 70cm (approximate nest depth) at a location that was mostly frequented by nesting turtles. It was set to record temperatures every 30 minutes from which a daily average was taken. The logger was retrieved every three months and the data downloaded using the Hoboware program. The logger was then re-launched and the measurements taken for an extended period of three months. Mean monthly air temperatures were obtained from the Kenya Meteorological Department and were used to derive monthly sand temperature measurements for months which had no *insitu* sand temperature records.

3.4 Data Analyses

Differences in nest abundance and track size between sites and between months were statistically compared using a one-way ANOVA. Variations in hatching success and clutch size between sites and between months were analyzed using Kruskal-Wallis one-way ANOVA test on ranks. A two-way ANOVA was used to determine the effect of months, site and interaction between site and months on nest abundance, clutch size and hatching success. One-Way ANOVA was also used to test for differences in beach characteristics between the sites. Before performing ANOVA and other parametric analyses (e.g. least squares regression), normality of data distribution was tested using Shapiro-Wilk test. Data were appropriately transformed where assumptions were not met or non-parametric alternatives were applied if transformations were not successful. Percentages of moisture content and of hatching success were arcsine transformed while monthly nest counts and clutch size was log-transformed before being used in the two-way ANOVA test as well as linear regressions. Agglomerative hierarchical cluster analysis was performed on nesting density at site in order to group sites according to levels of nest densities.

Least squares linear regression was performed to determine the relationship between sand temperature and air temperature and the relationship was then used to predict sand temperatures in months without temperature logger records. The relationships between distance from high tide line (HTL) and nest abundance, and between moisture content and hatching success were also determined using a least squares linear regression. Stepwise multiple regression was performed to determine the important predictors (clutch size, moisture content, pH, conductivity, sand structure, distance from HTL) of hatching success and nest abundance.

Classification and Regression Tree (CART) models (Breiman et al., 1984) were used to determine the important predictors of nesting activity and hatching success. The results were then compared with that of multiple stepwise regression. Ecological variables often have non-linear relationships with high levels of interactions not easily captured by parametric models. CART models are a non-parametric alternative to regression models that recursively partition the data set into increasingly homogenous groups with respect to the response variable (Breiman *et al.*, 1984). The tree is structured hierarchically, with the undivided data set at the top (root node), followed by binary splits of the predictor variables (branches) in order of importance, ending at the terminal nodes (leaves) with the response variable. The following predictor variables were used in the CART models to determine the important predictors of relative nesting abundance and hatching success; distance from HTL, moisture content, pH, conductivity, sand grain size, clutch size, and beach length. A classification Tree Analysis was used to model nesting abundance. The nesting abundance was categorized into three relative response variables; low (0-5 nests), medium (5-20 nests) and high (>20 nests). The influence of the predictor variables on the abundance categories was then determined by using a classification tree. All statistical analyses used in the study followed (Sokal and Rohlf, 1994) and were performed using JMP version 9.0.2.

CHAPTER FOUR

RESULTS

4.1 Historical trends in nesting activity

Nest counts of green turtles monitored on seven beaches on the Kenyan coast by the Baobab Trust has generally been increasing gradually over the years (1991-2012) as shown by the fitted second order polynomial trend line (Fig. 2). The trend line shows a slight decrease in the overall rate of increase of the nests during the period. The number of nests displays large inter-annual variations with an initial gradual rise in number between 1991 and 1995. High peaks in nesting were recorded in the years; 1997, 2001, and 2008 with a total of 56, 87 and 195, nests, respectively. Low points in nesting were recorded in the years 1996, 1998, 2002, 2004, 2009, and 2012 (Fig. 2). Over the 22 year period, a total of 1,154 green turtle nests have been recorded cumulatively in the beaches. The annual number of nests ranged from 3 (in 1992) to a maximum of 195 (in 2008) with a mean of 69.91 ± 11.77 nests per year (Fig. 2).

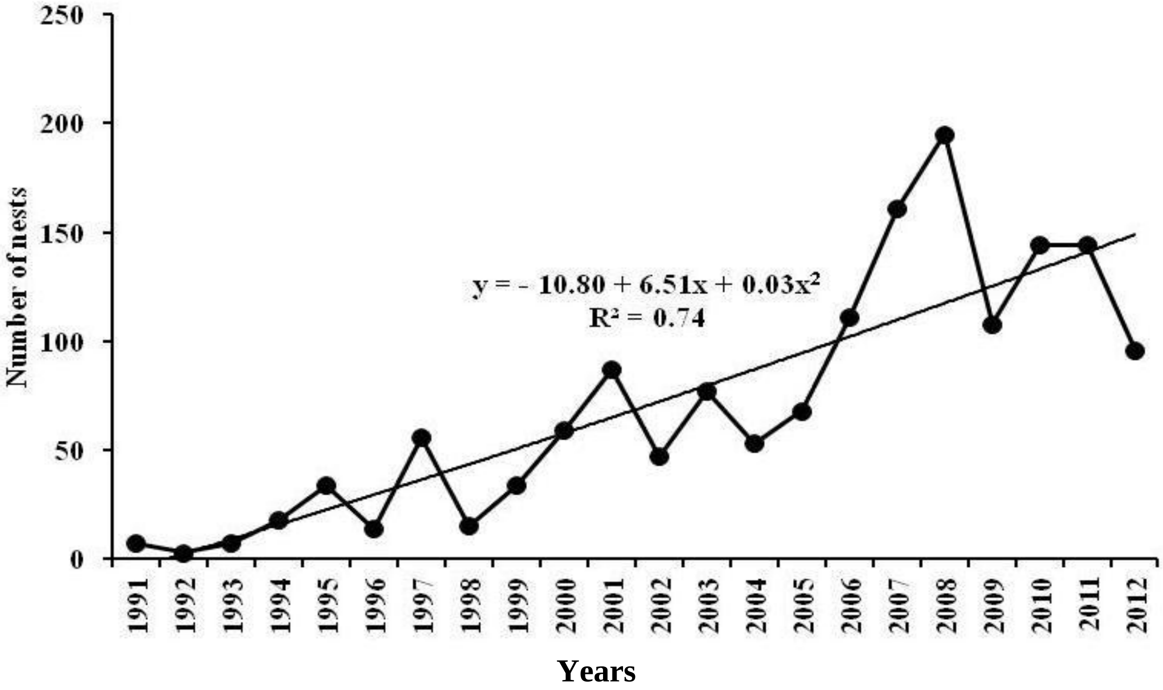

Figure 2: **Annual variation in nest counts at the beaches monitored by the Baobab Trust in coastal Kenya. The continuous line is the two-order polynomial trend line.**

4.2 Nesting activity and hatching success

The tracks measured at different sections of the Bureni beach were variable in sizes (Plate 1). The mean track size for all the sections of the beach was 104.53 ± 1.42 cm. The largest track was 127 cm while the smallest was 79 cm. Results of a One- way ANOVA showed no significant difference in mean track size between the beach sections ($F_{0.5,2} = 2.15$; $p = 0.13$) likely indicating similarity in the size of green turtles nesting in the beach sections at Bureni.

Table 1: Number (n), means and ranges of the track dimensions of the green turtles at Bureni beach, north coast of Kenya during the study period

Beach section	n	Mean ± SEM (cm)	Max (cm)	Min (cm)
Bureni Zone 1	33	105.09 ± 1.76	127	79
Bureni zone 2	17	105.82 ± 2.51	126	81
Bureni zone 3	4	94.5 ± 5.36	103	79
Total	54	104.53 ± 1.42	127	79

Results in Table 2 show that nesting beaches totaled 10.3 km in length with the individual beaches ranging from 0.15 to 4.74 km in length. A total of 156 nests were recorded during the study period ranging from 6 nests at Jumba ruins to 54 nests at Bureni beach. The most densely nested beach was English point (6.7 nests per km) while the least was Kikambala (0.4

nests per km) (Table 2). The highest hatching success was recorded at Nyali (95.60%) while Bureni had the lowest hatching success (81.47%). The overall mean hatching success was 87.35 ± 1.56 % for the beaches (Table 2).

Table 2: Spatial distribution of nesting activity of the green turtle at the beach sites during the study period. Beach locations are shown in Figure 1.

Beach site	Beach length (km)	Total number of nests	Nesting rates #/month ± SEM	Nest density #/Km	Average clutch size	Hatching success (%)
Bureni	1.08	54	4.50 ± 1.52	4.17	108 ± 3.83	81.47
Kikambala	4.74	25	2.08 ± 0.79	0.44	96 ± 7.31	93.09
Mwanamia	0.15	8	0.67 ± 0.28	4.44	124 ± 8.25	88.38
Jumba ruins	1	6	0.50 ± 0.19	0.50	119 ± 8.48	94.67
Msumarini	0.31	20	1.67 ± 0.45	5.38	105 ± 6.78	90.73
Kijipwa	0.35	4	0.33 ± 0.58	0.95	102 ± 6.82	94.00
Vipingo	1.47	14	1.17 ± 0.22	0.79	108 ± 4.76	94.22
Nyali	1	9	0.75 ± 0.42	0.75	123 ± 10.79	95.60
English point	0.2	16	1.33 ± 0.31	6.67	118 ± 8.33	94.79
Totals	**10.3**	**156**	**13 ± 0.42**	**1.3**	**109 ± 3.27**	**87.35**

Atleast eight clusters were identified from the hierarchical agglomerative cluster analysis (Fig. 3). Of the eight, two main clusters consisting of high nesting density sites (X: Bureni, Mwanamia, Msumarini and English point) and low nesting density sites (Y: Jumba ruins, Kikambala, Kijipwa, Nyali and Vipingo) were identified. Three sub-clusters of high nesting density sites (>4 nests per km) were formed by Bureni and Mwanamia, Msumarini, and English point beaches (Fig. 3). The low nesting density (~1 nest per km) site cluster also divided into three sub-clusters identifiable as Jumba ruins and Kikambala, Kijipwa, and Nyali and Vipingo beaches (Fig. 3).

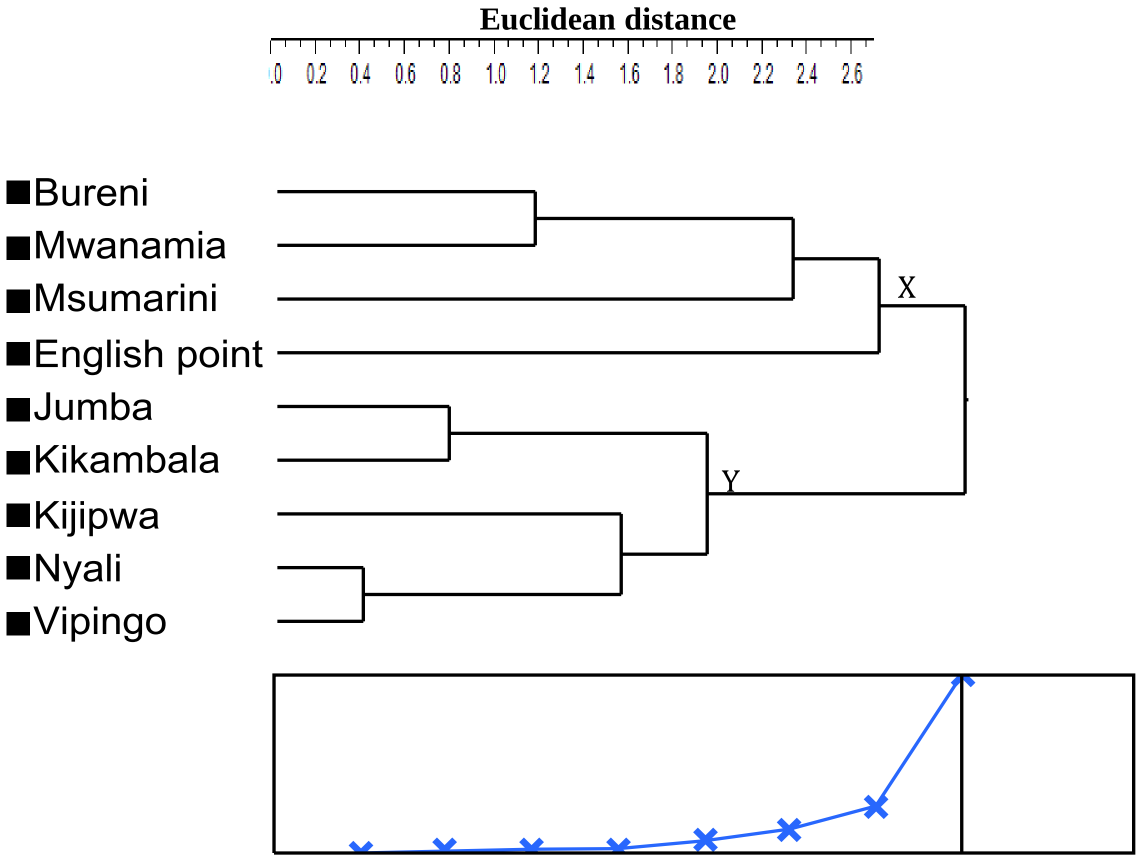

Figure 3: **A dendogram of cluster analysis of sites based on nesting density of the green turtle in coastal Kenya. The screen plot indicates the two main classes identified in the analysis.**

Peak nesting by the green turtles at beaches occurred in March (25 nests) and October (26 nests) (Fig. 4). High nesting effort (above annual average) was observed in the months of March-June and October. January- February, July-September and November-December periods had low nesting effort with densities below the annual average.

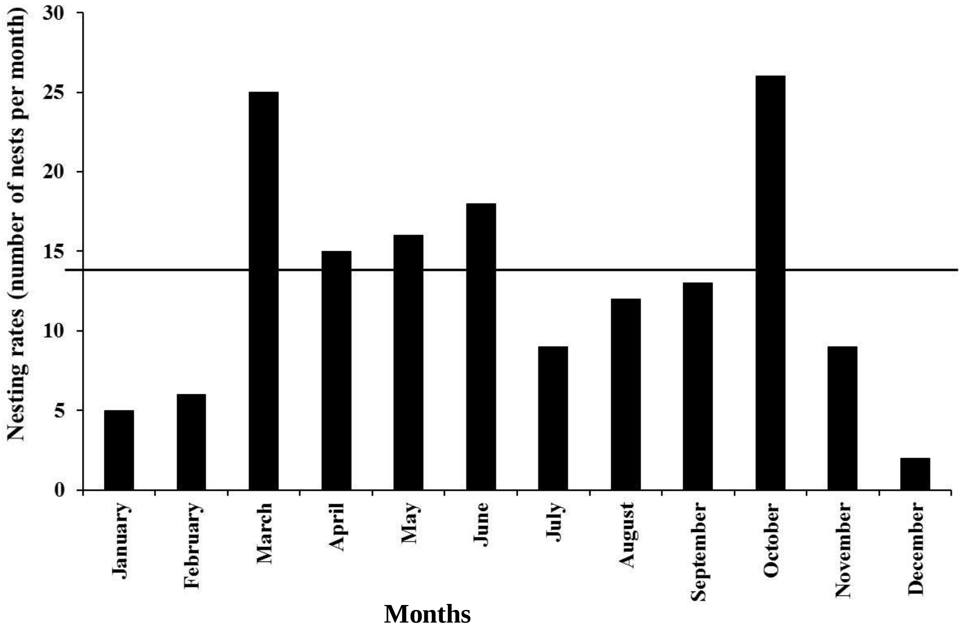

Figure 4: **Temporal distribution of nesting effort of the green turtles pooled for all the study sites in coastal Kenya during 2012. Horizontal line indicates annual nesting average.**

The highest nesting rates (nests per month ± SEM) was observed at Bureni beach with a mean of 4.5 ± 1.53 with most of the nests being recorded in March (33.33%), April (12.96%), and

May (18.52%) for this site (Table 3). Kikambala beach had the second highest mean nesting rate (2.08 ± 0.48) with the months of June and October both contributing 20% to the overall nests for the site. Mwanamia, Jumba ruins, Kijipwa and Nyali beaches all had less than 10 nests distributed in less than four months between January and October of the nesting season (Table 3).

Results of a two-way ANOVA indicated significant influence of months and site on the nest abundance at the studied beaches (month: $F_{0.5\ (2),\ 11}= 2.66$; $P = 0.005$; Site: $F_{0.5\ (2),\ 8}=4.09$; $p=0.0003$, respectively).

Table 3: **Spatial and temporal variation in nest counts (% annual contribution in parenthesis) of the green turtle at selected Beaches in coastal Kenya**

Site	January	February	March	April	May	June	July	August	September	October	November	December	Total
Bureni	4 (7.41)	4 (7.41)	18 (33.33)	7 (12.96)	10 (18.52)	6 (11.11)	1 (1.85)		1 (1.85)	2 (3.7)	1 (1.85)		54(34.62)
English point							2 (12.5)	8 (50)	6 (37.5)				16(10.26)
Jumba				1 (16.67)		3 (50)				2 (33.33)			6(3.85)
Kijipwa						2 (50)	1 (25)	1 (25)					4(2.56)
Kikambala			2 (8)	1 (4)	2 (8)	5 (20)	2 (8)	2 (8)	2 (8)	5 (20)	2 (8)	2 (8)	25(16.03)
Msumarini		1 (5)		1 (5)	3 (15)	2 (10)	1 (5)		3 (15)	7 (35)	2 (10)		20(12.82)
Nyali		1 (11.11)	1 (11.11)	1 (11.11)			1 (11.11)	1 (11.11)		2 (22.22)	2 (22.22)		9(5.77)
Vipingo			2 (14.29)	2 (14.29)	1 (7.14)		1 (7.14)		1 (7.14)	5 (35.71)	2 (14.29)		14(8.97)
Mwanamia	1 (12.5)		2 (25)	2 (25)						3 (37.5)			8(5.13)
Total	5 (3.21)	6 (3.85)	25 (16.03)	15 (9.62)	16 (10.26)	18 (11.54)	9 (5.77)	12 (7.69)	13 (8.33)	26 (16.67)	9 (5.77)	2 (1.28)	

4.3 Reproductive output

The overall mean clutch size (number of eggs ± SE) for all the sites pooled for the period in 2012 was 108.78± 26.97. The largest mean clutch size was 124 ± 8.25 in Mwanamia beach while the smallest was at Kikambala beach (96.26 ± 7.31) (Fig. 5). The mean clutch size averaged for all months did not show significant differences among sites (Kruskal-Walis: $\chi^2_{o.5, 8}$=13.57; p=0.09).

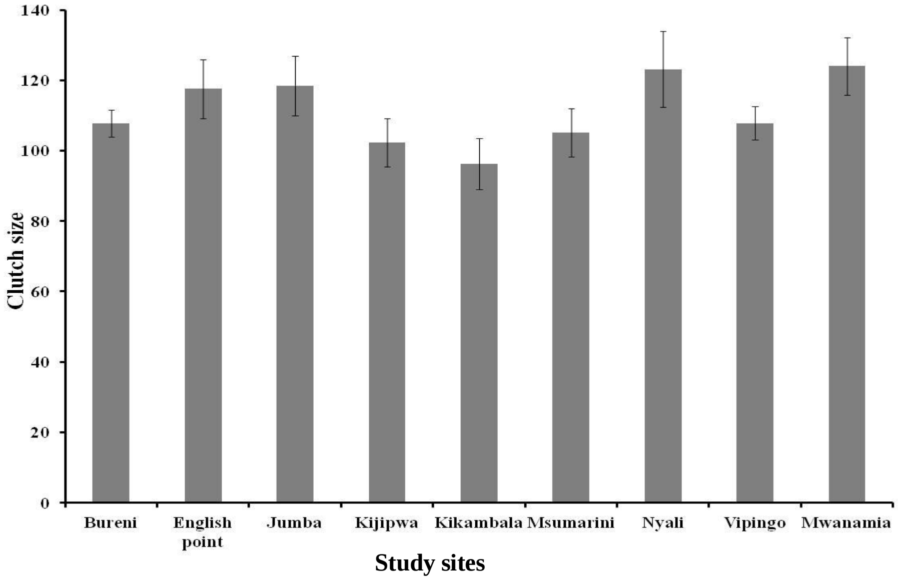

Figure 5: **Spatial variation in clutch sizes of the green turtles among the beach sites in coastal Kenya. Error bars indicate ± SEM**

At a temporal scale, the largest clutch size was recorded in October (163 eggs) while the lowest was in May (23 eggs) (Table 4). The mean clutch size per month pooled for all sites did not vary significantly across the months (Kruskal-Walis: $\chi^2_{0.5, 11}$ = 13.38; p=0.26, Table 4). The mean hatching success was between 74.81% (in January) and 95.87% (in August) for the *in situ* incubated nests with an overall monthly mean hatching success of 88.14% for the entire nesting season (Table 4). Results of a Kruskal-Wallis test showed no significant difference in mean monthly hatching success for the *in-situ* clutches ($\chi^2_{0.5,\ 11} = 17.86$; p = 0.09). For the translocated clutches, the highest mean hatching success among sites was recorded in July at 87.27% while the least was in January at 49.58% (Table 4). There was significant variation in mean monthly hatching success of the translocated eggs (Kruskal-Walis: $\chi^2_{0.5,\ 11} = 29.88$; p = 0.002) unlike the *insitu* eggs, with the highest success (87.27 %) in July and the lowest (49.58 %) in January.

Table 4: **Monthly mean clutch size (no. of eggs ± SEM) and hatching success of green turtles nesting at the nine studied beaches on the Kenyan coast. Number of translocated eggs in parenthesis.**

	Clutch size			Hatching success (%)	
Months(2013)	Mean	Range	Total # of nests	(*In situ* nests)	(Translocated nests)
January	134.25 ± 4.01	128-146	4(3)	74.81 ± 13.60	49.58 ± 8.17
February	112.67 ± 5.99	93-138	6(2)	82.40 ± 6.40	69.94 ± 10.01
March	110.04 ± 3.23	74-140	25(3)	84.56 ± 2.90	63.10 ± 8.17
April	115.14 ± 7.51	61-149	14(4)	87.23 ± 4.30	63.77 ± 7.08
May	92.1 ± 11.41	23-135	10(7)	89.74 ± 7.90	54.10 ± 5.35
June	109.12 ± 7.3	46-152	17(8)	81.39 ± 4.81	82.33 ± 5.01
July	115.88 ± 8.39	75-156	9(5)	94.78 ± 7.85	87.27 ± 6.33
August	101.17 ± 10.67	24-150	12(8)	95.87 ± 6.80	84.32 ± 5.01
September	121.67 ± 7.05	70-146	12(8)	93.50 ± 6.80	75.34 ± 5.01
October	103.33 ± 6.47	45-163	26(13)	91.33 ± 3.92	77.08 ± 3.93
November	112.33 ± 5.59	80-131	9(7)	91.90 ± 13.60	78.07 ± 5.35
December	110 ± 14	96-124	2(0)	90.12 ± 13.60	
Overall	109.54 ± 2.28	23-163	145(68)	88.14 ± 1.59	71.60 ± 2.06
χ^2,	13.38			17.86[a]	29.88[a]
p	0.26			0.09	0.002

[a] Kruskal-Wallis test

Results of a two-way ANOVA performed to investigate the effect of month and site on clutch size and hatching success independently showed no significant effect of the factors on clutch size ($F_{0.5\ (2),\ 11,\ 8}$=1.07; p=0.39) while, months and interaction between months and site had significant effect on hatching success of the eggs (Table 5).

Table 5: **Two-way ANOVA table for the influence of month, site and interaction between month and site on clutch size and hatching success of the green turtles on studied beaches in coastal Kenya.**

Source of variation	DF	SS	F	p
(a) Clutch size				
Month	11	0.32	1.57	0.12
Site	8	0.14	0.94	0.48
Month*Site	88	1.03	1.07	0.39
(b) Hatching success				
Month	11	0.9	3.31	0.002
Site	8	0.14	0.63	0.75
Month*Site	88	3.38	1.79	0.01

Hatching success for eggs that were incubated *in situ* varied significantly (Kruskal-Walis: $\chi^2_{0.5,\ 8}$ = 30.77; p = 0.0002) between sites (range: 81.47% - 95.79%) with the mean hatching success being 87.38 ± 1.56 (Fig. 6). Generally, hatching success of *in situ* clutches was higher than those of trans-located ones at all the sites (Fig. 6). Results of a Mann-Whitney U-test showed that the variation due to nature of incubation was significant (U = 547; p = <0.0001).

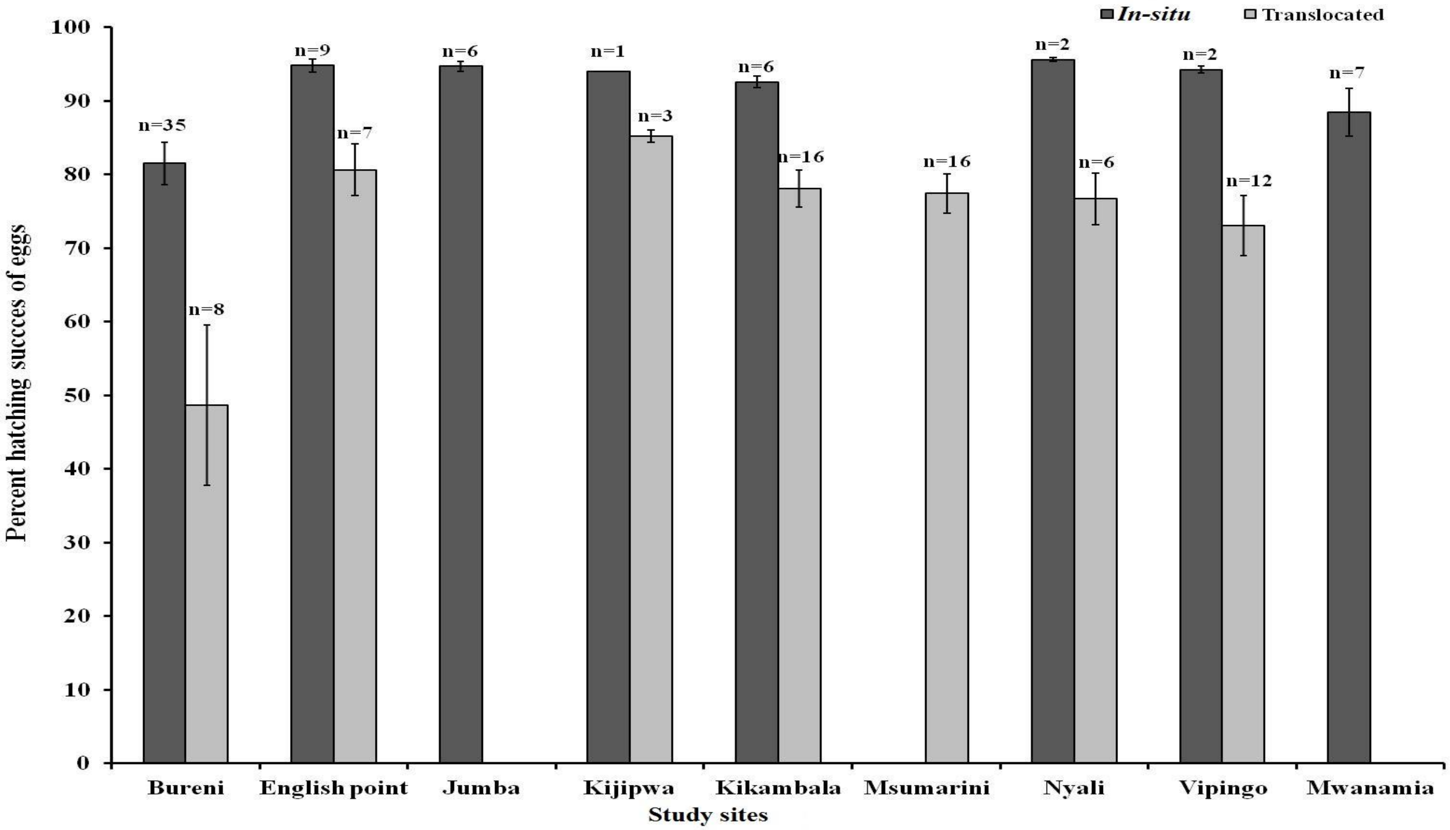

Figure 6: Spatial variation in hatching success of in situ and translocated eggs of the green turtles at different beaches in coastal Kenya (n =number of clutches, error bars indicates ± SEM)

4.4 Environmetal characteristics

4.4.1 Moisture content, pH and conductivity

The mean moisture content of the sand from all sites was 7.34 % ± 0.32 for samples from all the sites with a range of between 12.59% at Kikambala and 3.78% at Msumarini. The mean percentage moisture content of the sand samples varied significantly ($F_{0.5,\ 6}$ =8.58; p= <0.0001) between the beaches (Table 6). For pH, the mean was 9.41 ± 0.03 for all the sites and ranged between 9.94 at Kijipwa and 9.00at Kikambala. The mean sand pH did not vary significantly between the beaches ($F_{0.5,\ 6}$ = 1.86; p= 0.10). Conductivity (mmhos/cm) varied significantly between the beaches ($F_{0.5,\ 6}$ =8.05; p= <0.0001) with a range of 0.018 at Kikambala and 0.0004 at Msumarini.

4.4.2 Sand structure

Sand structure in Mwanamia and Jumba ruins was dominated (>50%) by coarse and medium sand sizes, respectively (Table 6). Msumarini and Vipingo beaches had greater proportions of very coarse and coarse sand contributing 73.33% and 72.54%, respectively, of the sand structure. Notably, Kikambala had greater proportions of fine sand (34.36%) compared to the other beaches (Table 6). Sand structure at Bureni beach was dominated almost equally by both coarse (38.85%) and medium sand grains (39%) with very low proportions of fine sand (0.16%) while, Kijipwa had greater proportion of coarse sand (43.27%) against 29.27% of very coarse sand and minimal proportion of fine sand (0.08%). At all the sampled sites, very fine sand represented the least proportion of grains (<1%) except for Kikambala beach which had 1.2% of fine very sand.

Table 6: Means of proportions (%) of grain size, % moisture content, pH and conductivity (mmhos/cm) of sand samples from the seven beaches studied on the Kenyan coast. ± indicates SEM

Site	Granules	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Moisture content	pH	Conductivity
Bureni	3.77 ± 0.47	17.17 ± 1.63	38.85 ± 1.57	39 ± 3.29	0.16 ± 0.07	0.03 ± 0.01	8.75 ± 0.56	9.49 ± 0.04	0.0069 ± 0.0009
Jumba ruins	1.51 ± 0.29	4.58 ± 0.84	13.24 ± 1.64	55.82 ± 2.23	22.95 ± 2.83	0.26 ± 0.08	6.63 ± 0.25	9.33 ± 0.08	0.0105 ± 0.0012
Kijipwa	1.28 ± 0.49	6.75 ± 0.94	34.62 ± 8.64	46.67 ± 3.43	11.05 ± 10.95	0.62 ± 0.6	5.06 ± 0.4	9.55 ± 0.02	0.0068 ± 0.0005
Kikambala	3.09 ± 0.88	9.19 ± 1.9	15.76 ± 1.14	31.12 ± 1.63	34.26 ± 4.77	1.2 ± 0.37	9.51 ± 0.5	9.25 ± 0.08	0.0152 ± 0.0013
Msumarini	7.56 ± 1.63	30.8 ± 6.92	42.53 ± 7.63	28.84 ± 2.89	2.73 ± 2	0.2 ± 0.16	5.6 ± 0.3	9.41 ± 0.11	0.0032 ± 0.0008
Mwanamia	5.58 ± 3.58	19.87 ± 1.21	50.92 ± 5.54	24.9 ± 3.86	1.83 ± 0.59	0.07 ± 0.03	7.06 ± 1.09	9.39 ± 0.07	0.0063 ± 0.0019
Vipingo	7.05 ± 1.3	29.27 ± 2.13	43.27 ± 2.65	15.84 ± 1.14	0.08 ± 0.03	0.03 ± 0.01	4.54 ± 0.27	9.41 ± 0.06	0.0054 ± 0.0005
ANOVA									
F	4.49	16.6	21.08	12.88	39.87	7.61	8.58	1.8639	8.05
p	0.0008	<.0001	<.0001	<.0001	<.001	<.0001	<.0001	0.1029	<.0001

4.5 Temperature measurements

There was a relatively strong relationship between mean monthly sand temperature and mean monthly air temperature for the six months in which *in situ* measurements were taken at Bureni beach (Fig. 7a). The least squares regression fit for the relationship between sand temperature (ST, ^{o}C) and air temperature (AT, ^{o}C) was derived as:

$$ST = 2.8762167 + 0.8699639 * AT, \; r^2=0.63, \text{(Fig. 7a)}$$

This relationship was then used to predict the nest sand temperature from February to July 2013 (Fig. 7b) when logger values were not available. The mean predicted temperature for the year was 29.28^{o}C ± 0.48^{o}C. Months between November and April (NEM season) had predicted temperatures of >30^{o}C compared to months between May and November (SEM period) with predicted temperatures of < 30^{o}C (Fig. 7b). The results show that there is a marked seasonal cycle, albeit of a limited range (less than 6^{o}C). There was inter-monthly variation in the predicted mean monthly sand temperatures with the peak sand temperature being recorded between December (32.23^{o}C) and January (31.11^{o}C) and low temperatures in September (25.92^{o}C). Months between March and September experienced a sharp decline in mean sand temperatures (Fig. 7b).

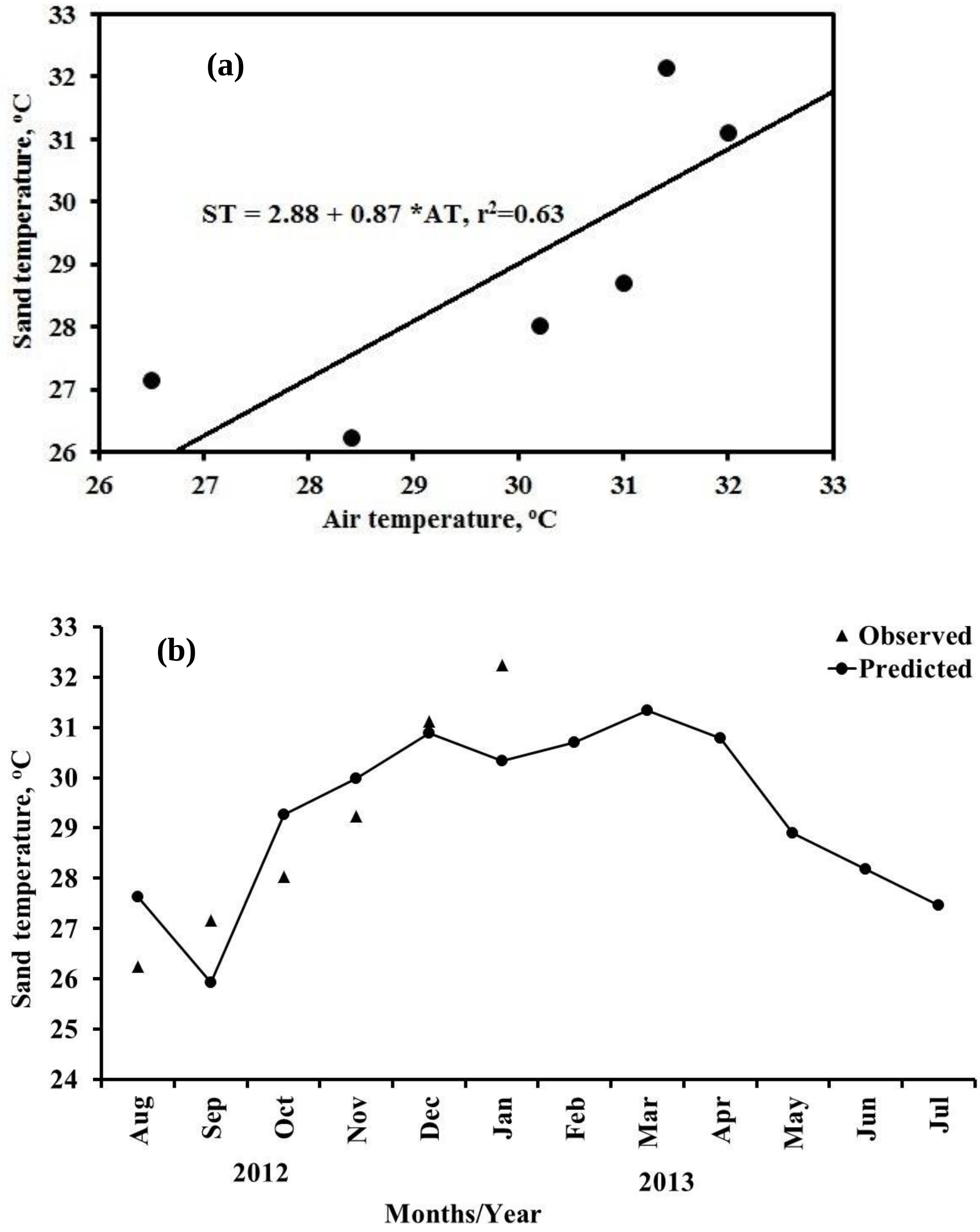

Figure 7: **a) Relationship between mean sand temperature and air temperature b) Temporal variation in predicted and observed mean sand temperatures at Bureni beach, coastal Kenya**

4.6 Relationships between clutch size, hatching success, nest abundance and beach environmental parameters

4.6.1 Influence of tidal level, moisture content and sand temperature

The nests were found between 0 and 20 m distance from the high tide level (HTL). The highest concentration of the nests was between 0 and 4 m from the HTL (Fig. 8). As the relationship between nest numbers and HTL was observed to be non-linear, an exponential regression was fitted to the data on number of nests (response) and HTL (predictor variable). A negative exponential regression between the variables was then derived as:

$$y = 1.68e^{-0.058x},\ R^2 = 0.75$$

The pattern of nest distribution described by this equation is shown in Figure 8. The trend from this equation shows a negative relation between number of nests and HTL

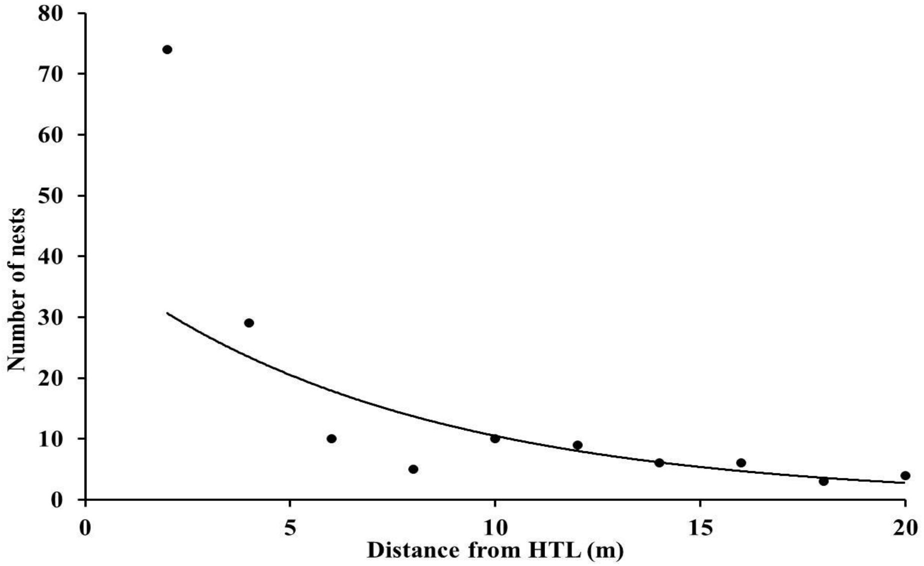

Figure 8: **Distribution of nests of the green turtles relative to the high tide line (HTL) at beaches in coastal Kenya. The curve is a negative exponential trend line.**

There was a slight and weak negative relationship between mean hatching success and mean sand moisture content at sites ($Y = 1.58-1.16x$, $R^2=0.29$, $p=0.27$) (Fig. 9a). The monthly number of nests showed a moderately strong positive relationship with mean sand temperature following a second order polynomial regression of the form:

$$Y = 193.58-13.05x+0.22x^2,\ R^2 = 0.53,\ \text{(Fig. 9b)}.$$

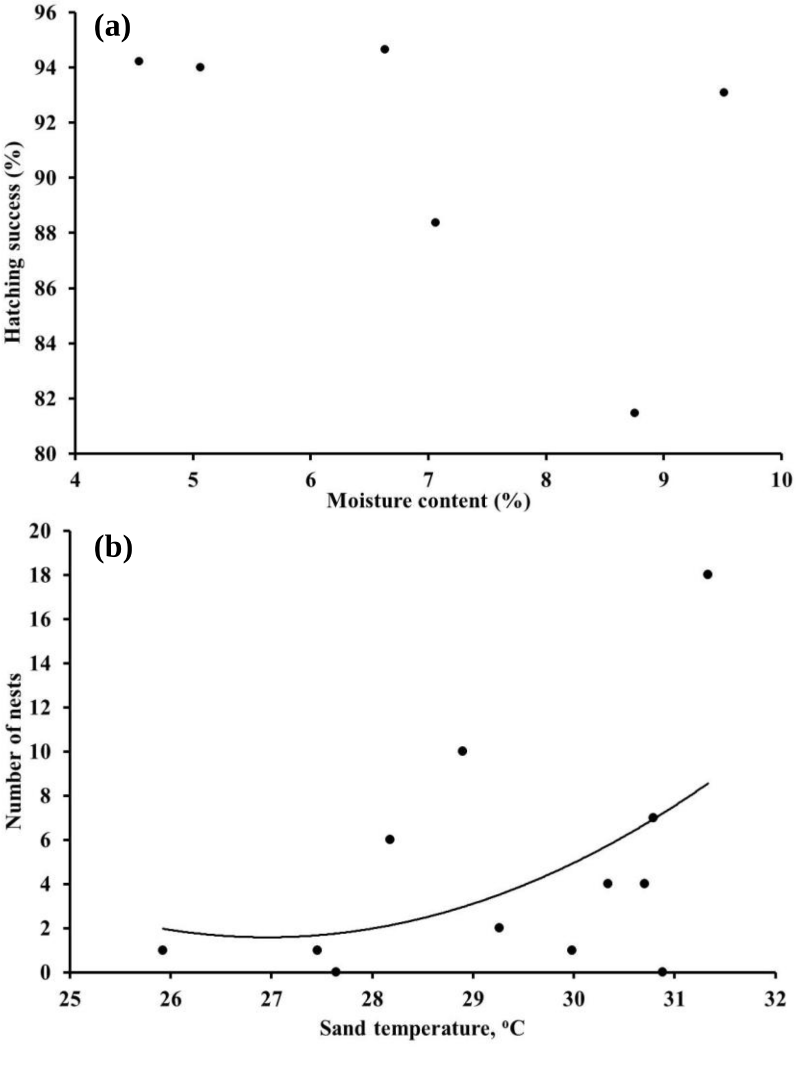

Figure 9: (a) Relationship between hatching success of the green turtle
moisture content at beaches in coastal Kenya
(b) Relationship between number of nests per month and monthly sand
temperature at Bureni beach.

4.6.2. Classification Regression Tree Analysis (CART)

The influence of a combination of environmental variables on nesting and hatching success was examined using Classification and Regression Tree analysis (CART). The regression tree for hatching success had 7 splits explaining 26.3% of the variance (Fig. 10). The pH, clutch size, distance from high tide line (HTL) and moisture content were identified as important variables in partitioning the variance in hatching success of the green turtle. pH was recognized as an important explanatory variable partitioning the observations into two groups, most important split occurred at the pH level of 9.43 with higher hatching success occurring at pH levels lower than 9.43 (Fig. 10). An important split occurred at pH<9.43 (91.81%) based on clutch size with higher hatching success (95.49%) occurring at sites with clutch sizes of less than 130 eggs, and moisture contents of greater than or equal to 7.06%. At sites with clutch sizes that were more than 130 eggs higher hatching success was observed at beaches that were greater than 1km in length. For sites with pH levels greater than 9.43, a further division based on pH was performed. Under conditions of pH >9.43 clutch size and distance from HTL were important explanatory variables leading to significant splits. Higher hatching success (85.02%) was observed at sites with clutch sizes that were less than 114 eggs and distances from HTL that were less than 12 m (86.71%) (Fig. 10).

Results of stepwise multiple regression in comparison to Regression Tree analysis, identified only clutch size as a significant predictor of hatching success ($F = 4.93$, $p = 0.03$). However, multiple regression results using moisture content (mc), pH, clutch size (cs) and HTL explained a small amount of variance in hatching success (HS) with the relationship;

Arcsin (HS) = 4.55 + 0.0027c + 0.007HTL - 0.35pH - 0.05mc, $r^2 = 0.16$, adjusted $r^2 = 0.097$, n = 61 nests.

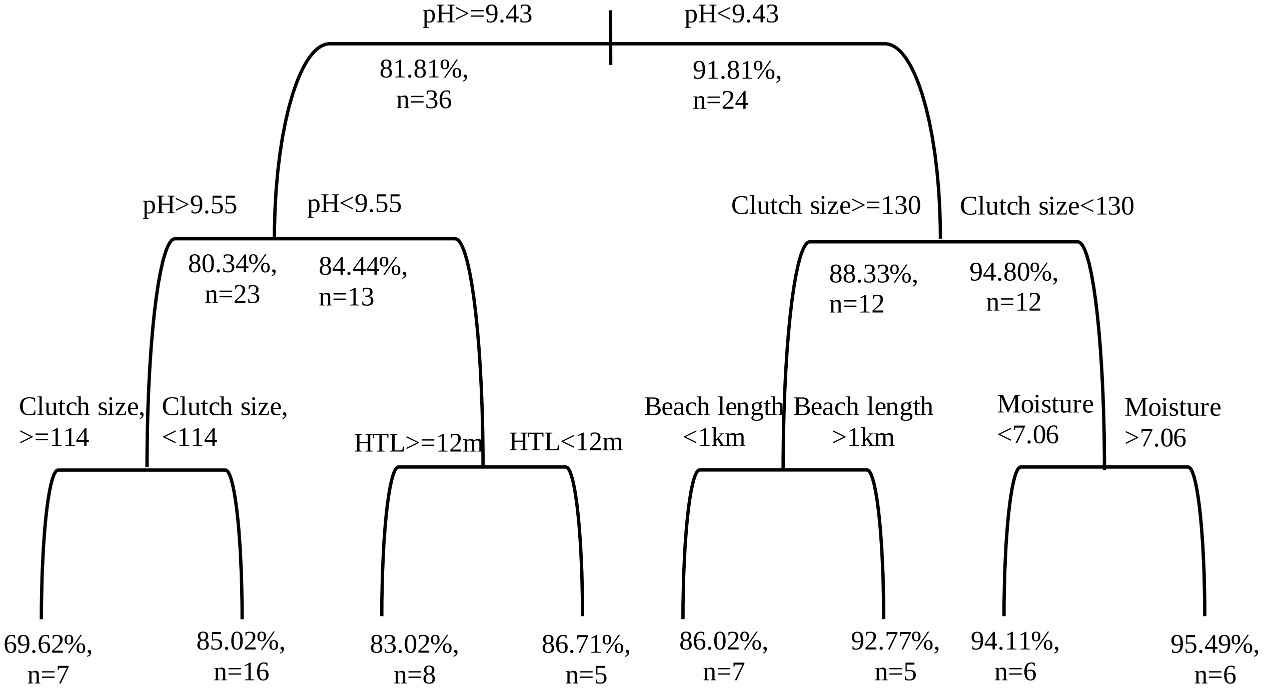

Figure 10: **Regression tree analysis for hatching success of the green turtle at beaches in coastal Kenya. Predictor variables and the level defining a split are labeled at each branch split. The sample size and % mean of the response variables are also provided.**

The Classification Tree for factors affecting abundance of nests had only 2 splits explaining 71% of the variance in nest abundance between the sites (Fig. 11). The Classification Tree demonstrated a reasonable accuracy with a low misclassification rate (probability that cases will be assigned to wrong class or category) of 8%. Conductivity and moisture content of the beaches were identified as important predictors of whether nesting abundance would be low, medium or high at sites. The most important split occurred at conductivity of 0.0098mmhos/cm. There was high nesting abundance at sites with conductivities of greater than or equal to 0.0098mmhos/cm (e.g. 25 nests in Kikambala) while, medium nesting abundance dominated sites with conductivity of less than 0.0098mmhos/cm. The second split occurred for sites with conductivity of less than 0.0098mmhos/cm (e.g. Vipingo=14 nests, Mwanamia=8 nests and Msumarini=20 nests) (Fig. 11). Under this conductivity conditions sites which had a mean moisture content of less than 6.63% had higher nesting abundance compared to sites which had greater than or equal to 6.63% moisture content which were dominated by medium level nesting abundance (Fig. 11).

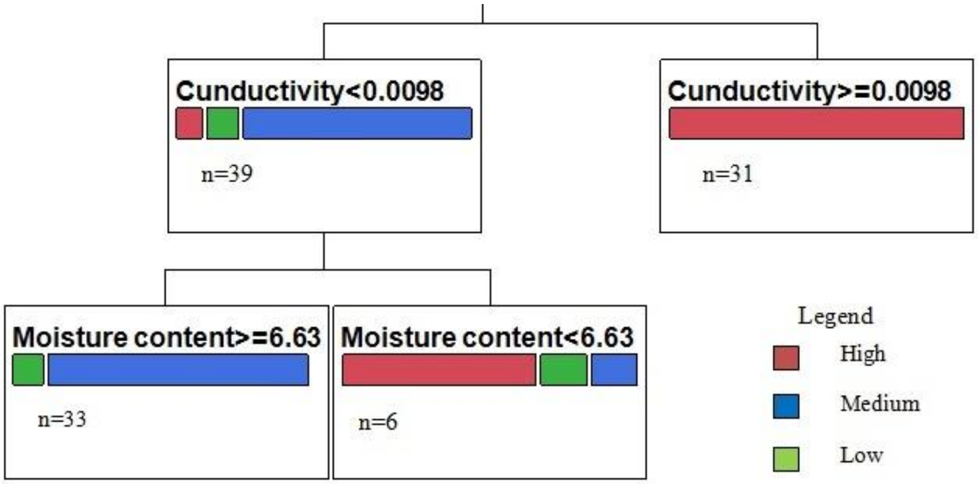

Figure 11: **Classification Tree for the three relative groups of nesting abundance indicating low (<5), medium (5-20) and high abundance (>20) of nests of the green turtle in coastal Kenya. R^2 = 0.71**

CHAPTER FIVE

5.0 Discussion

The historical data showed an increased nesting trend with large inter-annual variation in number green turtle nests recorded in coastal Kenya from 1991 to 2012. The positive long-term nest count trend suggests that the conservation efforts have been successful. However, the increased nesting trends may not necessarily mean increase in number of nesting females. Environmental variables as well as the period taken by green turtles to breed again i.e. re-migration interval, to the nesting beaches may influence the number of females ready to nest in a year (Chaloupka, 2001; Solow *et al.,* 2002). Therefore continued monitoring efforts are necessary in order to identify whether there have been subtle changes in the size of the Kenyan green turtle population. The large inter-annual variation in nesting effort is likely caused by changes in beach front conditions (Peterson and Bishop, 2005), inter-annual variations in quantity and quality of forage driven (Broderick *et al.*, 2002) mortality of females between nesting seasons amongst other factors. However, green turtles are generally known to display high inter-annual variability in magnitude of nesting (Limpus and Nichols 1987; Broderick *et al*. 2002).

The main peak nesting months for the green turtles takes place in March and October with low peak being November to January. The results contrasts with those of Okemwa *et al*. (2004) who described a general peak in turtle nesting along the Kenyan coast between the months of April and September, with main peaks being in May and June. It is likely that the disparity in peak nesting season between the two studies is as a result of inter-annual variability in timing of nesting by the turtles. For most populations of sea turtles, nesting occurs in a distinct season (Miller, 1996; Mortimer and Carr, 1987). Godley *et al.* (2001) suggested that prevailing temperatures are a more likely factor influencing the timing of a nesting season in turtles. Temperature was found to positively relate to green turtle nesting abundance at Bureni beach albeit with a little influence, indicating the importance of temperature in determining the onset of a nesting season.

The track width at Bureni beach ranged between 79-127cm and mean width (104.53cm ± 1.42) of turtles did not vary between the beach sections at Bureni beach indicating females nesting in different sections at the beach were of similar average size and perhaps belonging to a similar age or cohort. Other studies have shown nesting green turtles in Moheli Comoros to be of a similar size range (Lauret-Stepler *et al.*, 2010) perhaps indicating that age uniformity amongst turtles nesting within beach sections is a common occurrence.

The clutch size of the green turtles from this study ranged from 23-163 eggs. The clutch sizes did not vary significantly between beaches and months in this study. Further, interaction between months and sites did not show any significant effect on the clutch sizes. Differences in clutch sizes have been indicated to vary according to body size of nesting females rather than to environmental variables (Gibbons, 1982). The body size of female turtles constrains the number of eggs that can be carried, and there is considerable variation in body size of nesting females in many populations (Bjorndal *et al*., 1983). Resource availability and energy budgets can constrain the allocation of resources by females to reproduction (Miller *et al*., 2003), and this can directly affect clutch size. However, from this study it is difficult to explain the apparent lack of variability in monthly clutch size in this study.

The hatching success for *in situ* clutches varied significantly between sites but not between months. The studied beach sections varied in many physico-chemical parameters possibly contributing to the differences in hatching success between the beaches. There was significantly higher hatching success for the *in situ* eggs compared to translocated ones. The intra- and inter-annual fluctuation in egg-hatching rates has been reported to be a major problem with egg translocation programmes (Piedra *et al.,* 2007). In many cases, successful hatching is lower among transferred clutches than in natural *in situ* nests that have not been manipulated (Ozdemir and Turkozan, 2006). The causes for reduced success for translocated eggs (as in this study) seem to include embryonic mortality induced by physical moving of the eggs (Limpus *et al.,* 1979) and the greater risk of contamination by microorganisms because of the higher density of nests in hatcheries affecting the quality of the incubation substrate (Shanker *et al.,* 2003; Ozdemir and Turkozan, 2006), including the effects of organic matter and microorganisms present in the sand (Clusella and Paladino, 2007).

The sand particle diameter and sand temperature did not influence the placement of nests at sites. However, texture and mineral composition of the sand are considered to be the properties correlated with clutch survival (Mortimer, 1990). A mean particle diameter less than 0.75 mm has been found to have maximum percentage of emergence success in green turtles (Mortimer, 1990). During the present study all the sites had greater proportions of sand that was between 0.5 to 0.25 mm (Coarse and medium sand, respectively) therefore likely facilitative of emergence success.

Moisture content and conductivity were identified as important factors influencing nest abundance at the studied sites following CART analysis. Salinity (inferred from conductivity) has been suggested as a cue for nest site selection (Wood and Bjorndal, 2000; Mortimer, 1990; Carr *et al.,* 1966). Johannes and Rimmer (1984) reported that beaches in Australia where green turtles nest have lower salt content in surface sand than do beaches where turtles do not nest. However, like moisture, conductivity/salinity would seem to be an unreliable long term cue for nest site selection because it is a highly variable factor that changes with rainfall and water table fluctuations. In addition, the concentrated salt solutions secreted by sea turtles from lachrymal glands (Lutz, 1997) would probably interfere with the ability of sea turtles to discriminate sand salinity at micro scales. In this study high nesting abundance was observed at sites with conductivities of greater than 0.0098mmhos/cm.

The pH, clutch size, HTL, moisture content were identified as important factors influencing the hatching success of green turtle eggs following CART analysis. Ditmer and Stapleton (2012) found a positive effect of clutch size on hatching success in hawksbills where hatching success increased with larger clutch size but Mortimer (1990) found no significant relationship between clutch size and hatching success. In this study, clutch size was additionally determined as the only significant predictor of hatching success following the multiple regression analysis.

A significant negative exponential relationship was found between nest placement and HTL. Nests were located within 20 m from high tide level (HTL) with the highest concentration of nests being observed within 4 m from the HTL. Wood and Bjorndal (2000) suggested that the nest placement must avoid being too far away from the sea (to avoid eggs desiccation, misorientation or hatchlings predation) or too close to HTL (to avoid inundation or wave erosion). Kamel and Mrosovsky (2004) suggested that sea turtle females may have developed the ability of placing their nests at intermediate distances from the HTL as a response to these opposing pressures. Results from this study showed a weak negative relationship between hatching success and moisture content. The eggs of sea turtles are non-cleidoic and they continuously import water from the surrounding soil through their flexible shell (Venkatesan, 2004). Hence, optimum moisture content in the nest soil is a requisite for successful development of the embryo. Mortimer (1990) observed that the hatching and emergence success of the green turtle depended on the percentage of sand moisture content at Ascension Island. In his study the highest hatching and emergence success was observed in the nests located within 20 m from the HTL matching with the range of nest placement found in the present study. The lack of strong influence of moisture content on hatching success in may relate to temporal variations in egg physiology (Spencer and Janzen, 2011) in addition to other factors.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The green turtle nesting activity has increased significantly over the years with apparent changes in peak nesting season in relation to previous studies. The study showed significant spatial differences in nest abundance and nesting rates possibly explained by the significant variations in most of the physico-chemical characteristics studied at the beaches. Hatching success of *in situ* incubated eggs was found to be significantly higher than of translocated eggs. The study showed significant temporal variation in hatching success of translocated eggs. It is concluded from the present study that the HTL in addition to conductivity and sand moisture content of the sand influences nesting activity by the green turtles. Furthermore, moisture content, pH, HTL, nature of egg incubation (*in-situ* or translocated) and clutch size were determined as important factors influencing hatching success of green turtles in coastal Kenya. The results of this study provide useful insights into how various environmental, and nest-site specific covariates influence sea turtle hatching success rates and nest abundance.

6.2 Recommendations

Following the results of this study, the following recommendations are made;

- The knowledge that beach characteristics influence nesting, and given that turtles return to specific beaches to nest indicates that beaches may have distinct populations of turtles requiring spatially explicit management of green turtle populations in Kenya.

- *In situ* incubation methods within the beaches to avoid the shortcomings of translocation of eggs, should highly be advocated for conservation of the green turtle as hatching success has been found to be higher for *in situ* eggs compared to translocated ones. Additionally, beach monitoring initiatives should be scaled up to conserve eggs, nesters, hatchlings and to minimize beach development on nesting grounds.

- Further research is needed to develop a more complete understanding of the drivers of hatching success and nest site selection in beaches along the coastline of Kenya in relation to beach slope, vegetation and beach development.

- More monitoring studies on the green turtle are required to identify whether there have been significant changes in the size of the Kenyan green turtle population over the years for purposes of informing conservation strategies.

- The lack of strong influence of moisture content on hatching success in this study will require further investigations but may relate to temporal variations in egg physiology (Spencer and Janzen, 2011) in addition to other factors.

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APPENDICES

Appendix I: Spatial distribution of the studied beaches

Beach	**Latitude**	**Longitude**
English point	-4.06o S	39.69o E
Jumba ruins	-3.95 o S	39.77 o E
Kikambala	-3.91 o S	39.79 o E
Msumarini	-3.86 o S	39.81 o E
Kijipwa	-3.86 o S	39.81 o E
Viping	-3.85 o S	39.82 o E
Mwanamia	-3.77 o S	39.84 o E
Bureni	-3.83 o S	39.82 o E

Appendix II: List of tools used during the study

Tool	Activity
Flexible tape measure	Measurements of track sizes and intervals of sand sampling stations
Cylindrical plastic core	Drawing of sand samples from the beaches
Aluminum foils and plastic vials	Storage of sand samples
Weighing machine	Weighing of sand samples
Oven	Drying of sand samples
Sieves	Particle size analysis
Mechanical shaker	Remixing of sand samples
Laboratory test tubes	Holding and mixing sand samples with de-ionized water
TDS meter	Recording of conductivity measurements
pH meter	Measurements of pH
Hobo pro V2 temperature logger	Recording of sand temperatures
GPS	Recording of GPS coordinates