Nesting habitat preferences and nest predation of green turtles (Chelonia mydas) in the Bijagós Archipelago, Guinea Bissau

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In wildness is the preservation of the world.

Thoreau
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ABSTRACT

The nesting process requires sea turtles to choose among beach habitats that ensure a successful development of eggs and a low risk of mortality due to predation. The nesting habitat preferences of green turtles (Chelonia mydas) in João Vieira Island were analysed, as well as the proportion of emergences resulting in a successful nesting event and the effects of lunar and tidal phases on the nesting behaviour. The susceptibility of nests to predation at the different habitats were also analysed and nest predation rates were compared with the ones of Poilão Island. Of the habitat features evaluated (offshore bathymetry, slope, distance from highest spring tide line to forest, cliff height, vegetation height, ghost crabs burrows, and sand characteristics i.e. colour, grain size, pH and albedo), beach slope and vegetation height appeared to have the greatest influence on the emergence decision. Nevertheless, the distribution of successful nesting attempts revealed that green turtles showed a strong preference to nest on supra-littoral low height herbaceous vegetation areas. In addition, many unsuccessful nesting attempts were observed on shrubland. Green turtles nests on João Vieira experienced a severe predation (76%) by monitor lizards (Varanus niloticus) during the first 10 days after oviposition. No evidence of predation, or of predation attempts was found on Poilão. These differences between islands suggest that the extremely high nest density occurring in Poilão may reduce per-nest predation rates due to predator satiation. This study has made important findings on the habitat preferences of green turtles nesting in João Vieira, and provided basic ecological information about the nesting process and on the nest predation risks. The results also allow to better informing on the need of adequate monitoring and protection strategies.

Keywords: sea turtles; Chelonia mydas; nesting site selection; predation; monitor lizards; Guinea Bissau.
RESUMO

Para qualquer animal ovíparo o processo de nidificação tem consequências importantes para o sucesso reprodutor da fêmea. Um dos períodos mais vulneráveis do ciclo de vida das tartarugas marinhas é a fase embrionária uma vez que os ovos são deixados sem cuidados parentais durante o seu desenvolvimento. Quando uma tartaruga marinha emerge numa praia para desovar, geralmente encontra um habitat heterogéneo, e o local selecionado para a colocação dos ovos pode afetar a sobrevivência e o desenvolvimento da sua prole, assim como a sua própria sobrevivência. Este processo de seleção requer que as tartarugas marinhas escolham habitats de nidificação que garantam o desenvolvimento dos seus ovos com sucesso e com o menor risco de mortalidade destes e das fêmeas devido a uma possível predação. A intensa predação dos ninhos das tartarugas marinhás pode ter consequências demográficas importantes a longo prazo.

O presente estudo foi realizado nas ilhas de João Vieira e Poilão, no Parque Nacional Marinho de João Vieira e Poilão, situado no extremo sudeste do arquipélago dos Bijagós na Guiné-Bissau. A população de tartarugas verdes (Chelonia mydas) que nidificam nesta região é de particular interesse. Cerca de 7000 a 29000 ninhos foram estimados por ano na ilha de Poilão, tornando este o mais importante local de nidificação das tartarugas verdes em toda a África, e um dos mais importantes a nível mundial. Devido à elevada densidade de ninhos de tartaruga marinha, a ilha de Poilão tem sido foco de inúmeros estudos ao longo das últimas duas décadas. Apresentando menores densidades de nidificação assim como diferentes níveis de predação, as restantes ilhas têm recebido menor atenção, o que também é devido a limitações financeiras, técnicas e científicas. Com o presente estudo pretendemos compreender as preferências das tartarugas marinhas que nidificam na ilha de João Vieira e os fatores bióticos e abióticos que podem influenciar essas preferências. Além disso, na ilha de João Vieira os efeitos causados pela predação poderão afetar significativamente os ninhos das tartarugas verdes. Assim, foi também determinada a taxa de predação e a susceptibilidade à predação dos ninhos em diferentes habitats, comparando posteriormente estes resultados com as taxas de predação na ilha de Poilão.

O estudo de caracterização das preferências de habitat para nidificação ocorreu na ilha de João Vieira entre 6 e 30 de setembro de 2011, durante 25 dias consecutivos. Foram
medidas as variáveis ambientais que poderão influenciar a saída de uma tartaruga marinha da água em determinado local, as que poderão influenciar a preferência por determinado local para a postura, e ainda as que poderão levar uma tartaruga a desistir de desovar. Também foram analisados os efeitos das fases lunares e das marés sobre o comportamento de nidificação. Todas as ocorrências foram identificadas e a sua posição registada com um GPS, sendo feita uma distinção entre ocorrências que resultaram numa postura (successful nesting) e as ocorrências que resultaram numa desistência (false crawl).

A ilha foi dividida em cinco diferentes praias, nomeadas de A a E e cada praia foi caracterizada segundo quatro diferentes habitats, classificados através de dados recolhidos no campo e utilizando dados de classificação de cobertura do solo: vegetação herbácea; vegetação arbustiva; vegetação arbórea/floresta sub-húmida; e falésia. Para a caracterização das praias da ilha foram estabelecidos 119 pontos regulares separados por 100 m. Nestes pontos regulares assim como nos locais onde foram registadas as ocorrências que resultaram em postura ou em desistência, foram analisadas as seguintes variáveis: batimetria (distância da costa à isóbata dos 10 m), declive da praia, distância da linha de maré alta à floresta, altura das falésias, altura da vegetação, número de tocas de caranguejo fantasma, e características da areia, i.e. cor, granulometria, pH e albedo.

Os resultados da distribuição dos ninhos na ilha de João Vieira revelaram que as tartarugas verdes, selecionam efetivamente determinados locais para a nidificação, e que este não é um processo que ocorre aleatoriamente ao longo das praias. Das variáveis ambientais analisadas, o declive da praia e a altura da vegetação parecem ter maior influência no local onde as tartarugas verdes decidem sair da água. Contudo, a análise da distribuição das posturas revelou que há uma forte preferência para a desova em áreas de vegetação herbácea na zona supralitoral. Além disso, foi estudada a distribuição das ocorrências que resultaram em desistência, uma abordagem normalmente não analisada em detalhe por outros autores. Muitas desistências foram observadas em áreas de vegetação arbustiva que se encontra no limite da linha de maré alta. Com base nos presentes resultados as tartarugas verdes parecem selecionar locais para a postura em João Vieira com um baixo risco de inundação pelas marés.

Para o estudo da predação em João Vieira, os ninhos foram monitorizados durante 10 dias após a postura sendo registado o tipo de predador e o destino de cada ninho (intacto ou predado). Quando ocorreu predação, o número de cascas de ovos foi contado e estas retiradas da área. Para complementar as observações diárias, foram também colocadas
camaras de filmar em alguns ninhos, permitindo obter um melhor conhecimento sobre os predadores e o processo de predação, e permitindo também comparar os resultados obtidos com as observações diárias.

Na ilha de Poilão, a monitorização foi feita durante 12 dias consecutivos, de 3 a 14 de Outubro de 2011, sendo registada a ocorrência, distribuição e intensidade de predação. Diariamente, 4 a 6 ninhos foram selecionados aleatoriamente em diferentes áreas (expostos ou sob arbustos), e marcados a fim de seguir o seu destino durante quatro dias após a postura.

Os ninhos das tartarugas verdes que desovam na ilha de João Vieira sofreram uma elevada taxa de predação (76%) por varanos-do-nilo (Varanus niloticus), essencialmente nos primeiros dias após a postura. Esta elevada taxa de predação pode assim ser um fator limitante para o sucesso reprodutivo desta espécie em João Vieira. Contrariamente, nenhuma evidência de predação, ou tentativa de predação foi encontrada na ilha de Poilão. Estas diferenças encontradas entre as ilhas sugerem que a densidade extremamente elevada de ninhos de tartaruga verde em Poilão pode reduzir as taxas de predação devido à saciação do predador.

Com base nos resultados obtidos, sugere-se que certos aspetos da predação na ilha de João Vieira sejam melhor investigados, incluindo uma boa compreensão da ecologia dos varanos, importância relativa da predação durante todo o período de incubação dos ninhos das tartarugas verdes, assim como o impacto da predação sobre o sucesso da eclosão. Estudos futuros na ilha de João Vieira, poderão ainda incidir no sucesso do nascimento, taxa de sobrevivência e sex-ratio das tartarugas recém-eclodidas, assim como nos possíveis impactos provocados pelas alterações climáticas, de forma a compreender melhor os impactos causados pela preferência por determinado tipo de habitat no sucesso reprodutor das fêmeas.

No presente estudo foram feitas importantes constatações sobre as preferências de habitat, informações ecológicas básicas relativas ao processo de nidificação das tartarugas verdes em João Vieira e os riscos de predação dos seus ninhos, permitindo-nos inferir acerca da necessidade de estabelecer melhores estratégias de monitorização e de proteção dos ninhos.

Palavras-chave: Tartarugas marinhas; Chelonia mydas; seleção de habitat de nidificação; predação; varano-do-nilo; Guiné Bissau.
# CONTENTS

ACKNOWLEDGEMENTS ........................................................................................................... I

ABSTRACT .............................................................................................................................. II

RESUMO .................................................................................................................................. III

1. INTRODUCTION ................................................................................................................. 1

2. METHODOLOGY ................................................................................................................ 6

2.1. STUDY AREA ................................................................................................................ 6

2.2. JOÃO Vieira Island ......................................................................................................... 8

2.2.1 Surveys, nest monitoring and data collection .............................................................. 8

2.2.2. Estimation of the total number of nests ................................................................. 8

2.2.3. Tidal and lunar phases ............................................................................................ 8

2.2.4. Map production ....................................................................................................... 10

2.2.5. Beach use and habitat selection ........................................................................... 10

2.2.6. Nest predation ....................................................................................................... 17

2.3. Poilão Island ............................................................................................................... 17

2.4. Statistical Analysis ..................................................................................................... 18

3. RESULTS .......................................................................................................................... 19

3.1 Nesting activities and estimation of the total number of nests ..................................... 19

3.2 Effects of tidal and lunar phases .................................................................................. 19

3.3 Beach use and habitat selection ................................................................................... 20

3.4 Spatial distribution of nests ........................................................................................ 26

3.5 Habitat features at nest location .................................................................................. 26

3.6 Nest predation .............................................................................................................. 28

3.6.1 Documented nest predation through video cameras .............................................. 28

3.6.2 Predation parameters through daily observations .................................................. 29

3.6.3 Comparison among beaches and habitats ............................................................... 30

3.6.4 Comparison with Poilão Island ............................................................................. 31

4. DISCUSSION ..................................................................................................................... 32

5. REFERENCES ................................................................................................................. 41
1. INTRODUCTION

For sea turtles the production of a next generation results from a synergy between several factors, including the ecological conditions in the foraging area, the energy budget of the reproductive female and the environmental conditions of the beach where nests incubate, which ultimately affect the development of the embryos (Miller et al. 2003). Nest placement has important consequences for reproductive success of any oviparous organism. In fact, one of the most vulnerable periods of their life cycle is the embryo stage, as eggs are left to incubate on the sand, and embryos develop and hatch without any parental care (Wood and Bjorndal 2000). When a sea turtle emerges on an oceanic beach to nest, she usually enters in a heterogeneous habitat, and the location she selects for her nests can affect her reproductive success, and therefore her fitness, through the influence on her own survival and the survival and development of her offspring (Bjorndal and Bolten 1992; Miller et al. 2003; Karavas et al. 2005; Caut et al. 2010).

It is not entirely clear why female sea turtles prefer some beaches over others to nest, or why they decide to emerge at a particular location along the chosen beach (Mortimer 1995; Wood and Bjorndal 2000). Thus, the identification of possible cues that might affect the nest site selection has received considerable attention over the years (Bjorndal and Bolten 1992; Garmestani et al. 2000; Kamel and Mrosovsky 2004; Ficetola 2007).

Sea turtles are likely to use multiple cues in the selection of the nesting site, but it is not possible to state whether they use an association of environmental features or if they assess each feature separately (Mazaris et al. 2006). Results from several studies that have assessed potential indicators of nest site selection have identified multiple features which include: open offshore approaches, beach width, beach slope, vegetation cover of the beach, and sand characteristics (i.e. salinity, grain size, pH, organic and water content, conductivity, temperature and albedo) (Garmestani et al. 2000; Wood & Bjorndal 2000; Hays et al. 2001; Karavas et al. 2005; Foley et al. 2006). There is no single variable that can be generalized to all nesting sites (Miller et al. 2003) and variability is extremely high, from species to species and also within a given species from rookery to rookery (Mortimer 1990), and some authors suggest that nest placement by sea turtles is a random process or that selection is equivocal (Bjorndal and Bolten 1992; Hays et al. 1995; Kamel and Mrosovsky 2004). Sea turtles tend to nest on dynamic beaches, where the environment
may not be predictable from one nesting event to the next one, and therefore some authors defend that sea turtles may have evolved a nest placement strategy in response to their environment, by which individual nesting patterns may be random, resulting in an increased probability of successful some reproductive output (Bjorndal and Bolten 1992; Kamel and Mrosowsky 2004).

As stated above, nest site selection may vary at an inter-specific and intra-specific level. For example, female leatherback (*Dermochelys coriacea*) and green turtles (*Chelonia mydas*) tend to emerge on beaches with an accessible offshore approach and on foreshores that are relatively free of rocks, which may prevent the females to get injured during the emergence; they also seem to prefer deep-water access to the beach, reducing the crawl distance between the water line and the nesting sites (Eckert 1987; Mortimer 1995) and generally nesting above the high tide line (Kamel and Mrosovsky 2004). On the other hand, in Yucatan, Mexico, hawksbill turtles (*Eretmochelys imbricata*) were reported to nest on flatter beaches (Cuevas et al. 2010) while in Barbados the same species has a preference for deep-sloped beaches (Horrocks and Scott 1991).

Some sea turtle populations choose nest sites associated with beach vegetation (Horrocks and Scott 1991; Hays and Speakman 1993; Hays et al. 1995; Kamel and Mrosovsky 2004, 2005, 2006). Leatherbacks prefer to place their nests in the open sand (Kamel and Mrosovsky 2004), but loggerheads (*Caretta caretta*) and olive ridley turtles (*Lepidochelys olivacea*) nest preferably in the sandy area close to the supra-littoral vegetation (Lopez-Castro et al. 2004; Serafini et al. 2009), whereas hawksbill turtles tend to nest close to or in the vegetation (Kamel and Mrosovsky 2005). Several studies on green turtles showed that females preferred to nest on herbaceous vegetation and interface zones (Withmore and Dutton 1985; Wang and Cheng 1999; Turkozan et al. 2011), perhaps because these areas are located in the back shore where the flooding frequency by high spring tides is low. In addition, the roots and their derived organic materials can stabilize the beach substratum and increase the firmness of the sand, increasing the nesting success (Wang and Cheng 1999), while egg chambers on the open beach area are more prone to collapse during the digging process (Mortimer 1995; Ackerman 1997). However, if the vegetation cover is very high the root system becomes too dense to dig in (Chen et al. 2007).
If a nest is too close to the ocean, there is a greater likelihood of the eggs becoming saturated with seawater and fail to develop, or at a higher risk of being inundated by waves or washed away by beach erosion (Foley et al. 2006). If it is farther inland, there’s a greater risk of desiccation, roots from vegetation can invade the nest and destroy the eggs, nesting females, eggs and hatchlings will be more vulnerable to predation and hatchlings will be more prone to become disoriented during their way to the sea (Kamel and Mrosovsky 2004).

As the quality of beach sand may strongly influence nesting activity, embryonic development and hatching success (Mortimer 1990; Foley et al. 2006), one would expect that sea turtles use sand texture as a selection criteria for nesting sites as well. Sand composition of different nesting beaches varies greatly affecting critical features for embryonic development, such as drainage, gas and water exchange, and overall may be more or less favourable for maintaining a nest cavity (Mortimer 1995). Mortimer (1990) documented that the success of egg chamber construction is dependent on sand’s moisture and grain size; for example, the green sea turtle females have difficulties digging egg chambers in coarse, dry sand, typically making several trial nest chambers and re-emerging on successive nights before depositing their eggs on this type of beaches. However, only a few studies assessed the sand composition of the nesting beaches (organic matter, water and calcium carbonate content, pH, colour, grain size and sand albedo) as potential indicators of nest site selection (Mortimer 1990; Garmestani et al. 2000; Hays et al. 2001), but none of these authors found any relation between any of these features and sea turtle nesting site locations.

Overall, sea turtles may use different environmental cues during different stages of the nesting processes, i.e. emerging from the surf, ascending the beach, and finally placing the nest (Bjorndal and Bolten 1992; Wood and Bjorndal 2000). Therefore, a potential nesting beach must meet several minimum requirements, such as easy access from the ocean, a slope that avoids nests being frequently inundated by high tides (Mortimer 1995; Miller et al. 2003), adequate grain size and composition to allow successful nest construction, gas diffusion and exchange and temperatures conducive to egg development (Mortimer 1990). Additionally, the hatchlings must emerge to onshore and offshore conditions that enhance their chance of survival (Miller et al. 2003).
Another important factor that may affect egg and hatchling survival is the predation pressure, and this too can be related to the process of habitat selection by female sea turtles (Spencer 2002), although predation seems to act more as a random factor as female turtles have no control over predators and it may be impossible to predict which nests may or may not be predated and to what extent.

Although sea turtle populations appear to be most sensitive to mortality during the juvenile and early adult stages (Heppel et al. 2003), heavy nest predation can have long-term demographic impacts, whereas the survival of eggs and hatchlings are important for population recovery (Stancyk 1995; Leighton et al. 2010), and may be almost null in some populations (Brown and Macdonald 1995; Engeman et al. 2005), presenting obvious limitations to any recovery effort. Several predators of sea turtle eggs have been documented, including numerous species of mammals, monitor lizards, ghost crabs, fire ants, and other vertebrates and invertebrates (Catry et al. 2002, 2009; Blamires et al. 2003; Leighton et al. 2009; Mendonça et al 2010; Rebelo et al. 2012; Welicky 2012).

The spatial aggregation of nests can affect predation, either by increasing the risk through attracting predators to high-density areas (Marchand and Litvaitis 2004) or by decreasing it through predator satiation (Eckrich and Owens 1995). Eckrich and Owens (1995) compared predation rates on nests of solitary versus arribada nesters in olive ridley sea turtles (Lepidochelys olivacea) in Costa Rica during the first 24 hours after oviposition, and found higher mortality of solitary nests, concluding that nesting en masse affords some reduction of per-nest mortality.

Nest location has also been described as an important determinant of predation risk for sea turtle nests (Kolbe and Janzen 2002; Caut et al. 2006). Turtle nesting areas typically contain a mixture of vegetated and non-vegetated habitats, and habitat selection by both nesting turtles and nest predators can lead to uneven patterns of predation risk across the landscape (Leighton et al. 2008). Predation risk is also likely to vary temporally, both seasonally and throughout the embryo development, but such effects are not as well documented. Several authors have suggested that predation risk should change over the nesting season due to shifts in predator activity related to nest availability or to predator learning (Leighton et al. 2009). In addition, various studies have reported more frequent nest predation near the start of incubation (Leighton et al. 2009), but the relationship between daily predation risk and nest age has not been rigorously explored.
The green turtle (*Chelonia mydas*) nesting population in Guinea Bissau is of particular interest. Between 7000 and 29000 nests per year are estimated on Poilão, one of the smallest islands of the João Vieira and Poilão Marine National Park, making this island the most important nesting area for green turtles in the whole of Africa, and ranking amongst the most important worldwide (Catry et al. 2009). Other islands of this group, including João Vieira, also have good numbers of green turtle nests. Furthermore, several hundreds or even thousands of green turtle nests are laid in other Bijagós islands outside this park (Barbosa et al. 1998; Catry et al. 2002, 2010).

There are clear differences between the environmental characteristics, nesting densities of green turtles and probably in the nest predation rates of João Vieira and Poilão islands. The few studies about green turtles in the region focus on the nesting ground of Poilão and only limited monitoring has taken place over the past two decades in João Vieira (IBAP 2008). Some of those studies yielded relatively inconclusive results, in part due to insufficient funding and insufficient scientific technical assistance. In Guinea Bissau there is little evidence of nest predation by animals (Catry et al. 2002, 2009). But in some islands, such as João Vieira, with relatively important nesting grounds, monitor lizards are potential predators, and this pressure may significantly affect the green turtles nesting in this island.

In this study we analysed nesting habitat preferences and nest predation rates on green turtles nesting in João Vieira Island. Our main objectives were to: 1) to investigate the effect of the habitat features on the overall nesting preferences, by analysing the distribution of nesting attempts (then classified as successful nesting or false crawls) in the whole island; 2) to evaluate the importance of specific habitat features, such offshore bathymetry, beach slope, beach extent, cliffs height, vegetation height, presence of ghost crabs, and sand characteristics, such as colour, grain size, pH and albedo, on sea turtle nest locations; 3) to determine the susceptibility of nests to predation in João Vieira under different beach conditions and compare these results with predation rates in Poilão.

Overall, this study aimed at providing a better understanding of the importance of this island for green sea turtles, the implications that different biotic and abiotic factors may have in the reproductive success of this species, and to better inform on the need of adequate monitoring and protection strategies.
2. METHODOLOGY

2.1. Study Area

The present study was conducted on the islands of João Vieira and Poilão, in the João Vieira and Poilão Marine National Park (JVPMNP), situated in the extreme southeast of the Bijagós archipelago, Guinea Bissau (Fig.1). The Bijagós, the largest coastal archipelago of West Africa, comprises of 88 islands and islets, and covers an area of nearly 10000 km² off the coast of Guinea Bissau (Cuq 2001; Henriques and Campredon 2005). The climate is tropical, hot and humid, with seasonal rainfall, usually from May to November, which averages around 2000 mm per year in the coastal areas (Godley et al. 2003; Catry et al. 2009). Sandy beaches with deep-water approaches are uncommon, being found mainly on the outer islands. Although only about 21 of the islands are permanently or temporarily inhabited, the entire archipelago is used according to ancient management traditions (Limoges and Robillard 1991; Cuq 2001; Catry et al. 2009).

The archipelago currently has a population of about 25000 inhabitants, the vast majority belonging to the Bijagó ethnic group (Henriques and Campredon 2005). The resident populations live predominantly from subsistence agriculture; however there has been an increasing number of seasonal immigrants (mainly from Senegal) who fish in large canoes, targeting sharks, rays, barracudas, snappers, and other large predatory fish (IBAP 2007).

More than 95% of the 495 km² of the JVPMNP correspond to intertidal areas and shallow marine waters less than 30 m deep. The land permanently emerged consists mainly of four small main islands (João Vieira, Cavalos, Meio and Poilão) and a few islets, covering a total area of only 1500 ha (IBAP 2007). Among the reasons for the creation of the park was the protection of the largest population of green turtles in the eastern Atlantic, as well as of the important colonies of breeding seabirds and abundant fish resources. The park includes an extensive marine area where fishing is prohibited, to allow the recovery of the populations of some species of fish (IBAP 2007).

The Poilão Island is the southernmost and one of the smallest (43 ha) of the Bijagós archipelago; it is covered by a tropical forest and surrounded by a rocky subtidal reef of around 4 km, of which 2.3 km are sandy beaches (Catry et al. 2002; Godley et al. 2003). This rocky reef that surrounds the island prevents sea turtles to access the beaches.
in most of the perimeter during low tides. Poilão has no regular human settlements and is not used for agriculture or as a fishing base (Catry et al. 2010).

The João Vieira Island has a coastline of 12 km, 11 km of which correspond to sandy beaches, and is covered by tropical dry forest, savannah and sub-humid forest (Cuq 2001). João Vieira is the only permanently inhabited island of the JVPMNP. There are some small seasonally occupied tourist infrastructures, and temporary settlements of people from Canhabaque Island that frequently use the island to collect forest products (mostly palm fruits for palm oil production) and to cultivate rice (IBAP 2008; Catry et al. 2010).

Fig.1 - Location of João Vieira and Poilão islands within the João Vieira and Poilão Marine National Park in Guinea Bissau, West Africa.
2.2. João Vieira Island

2.2.1 Surveys, nest monitoring and data collection

Surveys were carried out on João Vieira Island to assess the occurrence and distribution of sea turtle nesting activities, to characterize the nesting habitat, and finally to register occurrence, distribution and intensity of nest predation.

Monitoring occurred during peak nesting activity from 6\textsuperscript{th} to 30\textsuperscript{th} September 2011 (25 consecutive days). Beaches were surveyed immediately after dawn, for a reliable identification of the emergences during the previous night. The beaches A, B and C were monitored every day, and beaches D and E every two days (Fig.2).

All emergences of females were identified and their position recorded with a GPS, making a distinction between fresh and old emergences (more than 24 hours) in beaches D and E. Nesting activities (or emergences) were classified as \textit{successful nesting} resulting in oviposition, and \textit{false crawls}, a natural behaviour whereby the female emerges on the beach without nesting, because it cannot find a suitable site, it is disturbed or for no discernible reason. Tracks were erased to avoid posterior counting. Nests were marked with a small numbered plastic tag in order to follow their fate in the following days.

2.2.2 Estimation of the total number of nests

Catry et al. (2002) made regular track counts between mid July and mid December 2000 on the neighbouring island of Poilão, and estimated a total of 9733 green turtle nesting activities for that year. Between 6\textsuperscript{th} to 30\textsuperscript{th} September 2000 (the same period of the present study), 2860 emergences (29.4\% of the total) were recorded on Poilão. The total emergences on the João Vieira island in 2011, was estimated by multiplying the number of emergences in João Vieira between 6\textsuperscript{th} and 30\textsuperscript{th} September by the inverse of the proportion of nests recorded on Poilão in that same period (in 2000), relative to the total number of nests in that year.

2.2.3 Tidal and lunar phases

To test if nesting events depended on the lunar and tidal phases, the Hydrographic Institute Tidal Chart from the Port of Bubaque (2011) was used to obtain tide height in each night. Since it was not possible to record the exact time of the nesting activities to relate it with the tide cycle, it was only had into account the highest tide of each survey day to infer any influence of the tides in the nesting activity.
Fig. 2 – João Vieira Island with the indication of the five different beaches.
Moon phases were divided into lunar quarters: plus and minus three days from the date of each phase, resulting in seven days per quarter. The lunar phases were categorized according to the intensity of the moonlight, as follows: 2 = full moon; 1 = first and last quarter; and 0 = new moon. Nests laid outside these ranges were not included in the analysis.

2.2.4. Map production

GIS provides powerful tools to store, display and analyse spatial ecological data. Virtually every aspect of sea turtle biology has a geographical reference and therefore can be considered as an event in a GIS (Florida Fish and Wildlife Conservation Commission 2001). A simple Garmin Geko GPS was used to record points, track-logs, and to build lines in the field. Polylines and points were imported. The GIS was developed on the ESRI ArcGIS 10.1 software, integrating images, database and other geographical data created with a number of different information sets, such as, data collected on field, nautical charts and land cover shape files. WGS84 / UTM zone 28N was used as the projection for all data collection. A nautical chart of the Channels of João Vieira Group with a 1/50 000 scale produced by the Hydrographic Institute of Portugal (1966) was used; the land cover shape files were provided by IBAP (Institute of Biodiversity and Protected Areas of Guinea Bissau) and produced in 2001 (Fig. 3). The ESRI Spatial Analyst was used to create raster layers, raster calculations and for nesting activity density analysis.

2.2.5. Beach use and habitat selection

The sandy coastline was naturally divided into five different beaches as follows: A (2.66 km length), B (0.90 km), C (2.35 km), D (4.26 km) and E (1.95 km) (Fig. 2).

Each beach is characterized by different habitats, and so, with the data collected on the field and the land cover shape classification provided by IBAP, four different habitats (Fig. 4 and 5) were defined as follows:

i) Herbaceous: supra-littoral vegetation of low height (lower than 0.6 m) above the highest spring tide line backing the beach;

ii) Shrubland: shrubs and isolated trees, normally reaching the border of the highest spring tide line;

iii) Sub-humid forest: dense and humid forest, normally reaching the border of the highest spring tide line;

iv) Cliffs: backing the beach (from 0.5 to 10 m high).
Fig. 3 – Coastal environment and land cover of the João Vieira Island.
Fig. 4 - Four different habitats classified for the João Vieira Island: i) herbaceous, ii) shrubland, iii) sub-humid forest and iv) cliffs.
Fig. 5 - Four different habitats classified for the João Vieira Island: i) herbaceous, ii) shrubland, iii) sub-humid forest and iv) cliffs.
To characterize the island’s shores, 119 regular points were established, set at a distance of 100 m from each other, where data was collected on several habitat variables listed below. These variables were also measured at the location of each nesting activity.

A total of 11 habitat variables were assessed for each regular point:

1. Presence or absence of rocky reefs;
2. Bathymetry (distance from the coast to the 10 m isobath);
3. Beach slope;
4. Cliff height;
5. Vegetation height;
6. Distance from the highest spring tide line (HSTL) to the vegetation;
7. Number of burrows of ghost crabs (*Ocypode cursor*);
8. Sand colour;
9. Sand albedo;
10. Sand grain size (µm);
11. Sand pH.

An additional variable was measured at the location of each nesting activity:

12. Distance from nest to highest spring tide line (HSTL);

The presence or absence of rocky reefs (1) was recorded at a distance of less than 100 meters from high tide line. All reefs were low-lying and covered by water during high tides.

Bathymetry (2) was measured with the GIS software, using as a baseline the nautical chart of João Vieira and then measuring, for each regular point, the distance from the coast to the 10 m isobath (in km). This variable was then extrapolated for all nesting activities located within a sector of 100 m around each regular point.

Beach slope (3), was measured every 500 m (on 24 of the 119 regular points), in transects set perpendicular to these, and then extrapolated for all regular points and nesting activities using the nearest measured point. A 10 m string was set horizontally (controlled by a level), between two vertical poles (Fig. 6). If the beach was wider than 10 m, more than one transect was measured. The height of the string on each pole was measured.
Beach angle was calculated through the following trigonometry formulas:

\[ \text{Beach slope} = \frac{(h_2 - h_1)}{d} \]

b) Beach slope angle (degrees) = ArcTan (Beach slope)

a) The beach slope is described as the ratio of the altitude change between poles 2 (h2) and 1 (h1) to the horizontal distance (d).

b) The beach slope angle is then described as the arctangent (ArcTan) of the slope.

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Fig. 6 – Method for measuring beach slope.

Cliff height (4) was visually estimated to the nearest meter.

Vegetation height (5) was visually estimated to the nearest meter, considering any dense vegetation with more than 0.6 m height.

The distance from the highest spring tide line to the vegetation (6), considering any dense vegetation with more than 0.6 m height, was measured using a measuring tape.

The number of ghost crabs (\textit{O. cursor}) burrows (7) was counted within a radius of 20 meters of each regular point or nesting activity.

To measure sand colour (8), sand albedo (9), sand grain size (10) and sand pH (11), 30 sand samples were collected from different areas scattered around the whole island, and located with GPS, where nesting occurs. A variety of situations were sampled, including sun exposed and shaded areas, open beach, within vegetation or inside the forest. It was then extrapolated for all regular points and nesting activities using the nearest sample.
The sand colour (8) of air-dried samples was quantified using the Munsell Colour System with a white background. For each sample the colour was matched to a chart number, which refers to the three elements of colour: hue, value and chroma (Munsell 1946). To analyse the sand colour, only the hue component was evaluated using the methodology proposed by Post et al. (1993), where the hue was transformed into ordinal data, on a scale ranging from red to yellow, establishing the following order: 10R = 1, 2.5 YR = 2, 5YR = 3, 7.5 YR = 4, 10YR = 5, 2.5Y = 6 and 5Y = 7.

The albedo (9) describes the fraction of the incident solar radiation reflected from a surface. A Red Tide Spectrometer from Ocean Optics, with a wavelength range of 350-1000 nm, was used to measure the reflectance of the sand, i.e. the albedo. Before measurements, the sand surface was smoothed. The light meter was held in a vertical position around 25 cm above the sand and pointing downwards, with no shadows being cast on the measurement area. The spectrometer was calibrated with a white card of barium used as our control measure of a known albedo of 100%. The Spectra Suite Spectrometer Operating Software was used for data acquisition. The software was programmed to make 10 consecutive readings from which means were calculated of the albedo of the sand within visible wavelengths (350–800 nm), and then the values of reflectance in the maximum sunlight wavelength (ca. 530 nm) were chosen for each sample.

Sand grain size (10) was classified by particle size analyses of 24h oven-dried samples, performed by using a series of sieves of 2.0 mm (pellets), 500 µm (coarse sand), 250 µm (medium sand) and 63 µm (very fine sand) (Folk 1974).

The sand pH (11), was measured by taking a 20 g oven-dried subsample and mixing it with de-ionized water in a 1:5 mixture. This mixture was stirred for 30 min and left for the same duration in stillness before a pH reading was taken.

The distance from the nest to the highest spring tide line (12) was measured with a measuring tape. When a nest was below the HSTL a negative value was recorded.
2.2.6. Nest predation

Nests were monitored during the daily surveys for 10 days after oviposition. Each day the type of predator and the fate of each nest (intact or depredated) were recorded. To identify the predator species the tracks were observed, but several times monitor lizards (*Varanus niloticus*) were found actually predating the nests. It was noted if a nest had been excavated by predators (monitor lizards, crabs or others), and if shells from predated eggs were present within or close to the nest. If there were eggs present, the number of shells was counted, and these were removed from the area in order to avoid double counting on the following days.

Nests were not followed after these 10 days monitoring, so no other data was collected on the nest fate or on the possibility of hatching success.

To assess if the daily observations were a good indicator of the level of predation and also to better document nest predation, video cameras (PlotWatcher Pro from Day 6 Outdoors) were placed in several locations along the beach. Using cameras also gave the opportunity to assess whether this method is a valuable tool to identify predator species and to get a better knowledge on their predation behaviour.

These cameras were not provided with night vision; however analysing the images just before sunset and after sunrise, it was possible to infer if there has been any predation during the night by observing the presence of tracks, evidences that the nest had been excavated or the presence of eggshells within or close to the nest.

Of the 175 nests surveyed, 22 were monitored through video cameras. Cameras were placed next to the nests during the first days after laying and were kept recording from one to three consecutive days. They were placed only next to nests located on beach A and on herbaceous areas, where nest density was historically higher, and risk of nest inundation by high tides was lower. Videos were then analysed, and it was noted if there were different species predating the nests, as well as the number of eggs predated each day.

2.3. Poilão Island

Surveys were carried out on Poilão Island during 12 consecutive days, from the 3rd to 14th October. The occurrence and distribution of sea turtle nesting activities were assessed, the nesting habitat was characterized, and finally were registered the occurrence, distribution and intensity of nest predation.
From all data collected in Poilão it will be only present the results regarding nest predation, in order to compare the predator species and the predation rates with the data collected in João Vieira. No video cameras were placed in Poilão Island. Each night, nests for monitoring were selected randomly in an interval of every 5 female turtles found, 4 to 6 turtles that were already laying eggs in different areas (exposed or under shrubs), and marked with a small numbered plastic tag, in order to follow their fate in the following four days after oviposition. The fate of these nests was noted as intact or predated (in this case, the type of predator was noted).

2.4. Statistical Analysis

The relation between the tides and the nesting activities was tested with the Pearson’s correlation coefficient. Chi-square tests were used to test the effects of lunar phases on nesting activities and the differential use of beaches and coastal habitats.

To understand which beach features may provide cues that green turtles may use when deciding where to dig their nests, the habitat features were analysed with: chi-square test for independence ($\chi^2$) to determine the independence of qualitative variables, and one-way ANOVA ($F$) to compare means from independent groups. The assumptions of these tests were analysed with the Kolmogorov-Smirnov and Levene test. Kruskal-Wallis ($H$) analysis was used whenever the homogeneity of variances was not met. To assess pairwise differences the post-hoc Tukey HSD comparisons were performed.

To analyse the predation results, the Spearman bivariate correlation analysis was used to compare the number of predated eggs recorded per day by the video cameras with the number of predated eggs counted during the daily surveys. To compare predation rates among beaches and habitats the one-way ANOVA and chi-square test for independence were used.

Statistic analysis was performed with Statistical Package for Social Sciences (SPSS) version 20.0.
3. RESULTS

3.1 Nesting activities and estimation of the total number of nests

During the 25-day survey on João Vieira Island, 246 emergences of green turtles were recorded: 175 (71.1% of the total) successful nesting events and 71 (28.9%) false crawls, with an average of 10 emergences per night (SD = 4.15, range = 3 – 17).

We estimated the total number of emergences of green turtles that occurred during the season of 2011 on João Vieira Island, considering the same September period of the present study on Poilão in the season of 2000. This resulted in an estimation of 838 emergences (596 successful nesting events and 242 false crawls) that may have occurred on João Vieira during the nesting season of 2011.

3.2 Effects of tidal and lunar phases

The survey began on the first quarter phase of the moon and ended on the new moon. Thus data used for this analysis was limited to the 21-day period starting on September 10th, which corresponds to three complete lunar phases: full moon, last quarter and new moon.

Differences were found between lunar phases ($\chi^2 = 6.262, p = 0.044$), evidencing a higher proportion of false crawls during the full moon phase (32.9%, n= 27), but also a decrease of the nesting activity throughout the lunar cycle (Table 1 and Fig. 7).

There was no correlation between the number of emergences and the tides heights ($r = 0.04$, n = 246, $p = 0.531$).

<table>
<thead>
<tr>
<th>Moon phase</th>
<th>Number of Successful Nesting</th>
<th>Number of false crawls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Moon</td>
<td>55</td>
<td>27</td>
</tr>
<tr>
<td>Last quarter</td>
<td>54</td>
<td>10</td>
</tr>
<tr>
<td>New moon</td>
<td>38</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 1. Green turtles (Chelonia mydas) nesting activity during the 21-day period surveyed through three moon phases.
Fig. 7 – Daily number of emergences and number of green turtle nests (Chelonia mydas) recorded during the 25-day survey, with depiction of the highest tide of the day, and the day of full moon and new moon phases.

3.3 Beach use and habitat selection

The recorded nesting activity for all the sampling beach units over the survey period is shown in Table 2. The nesting activities were significantly different between beaches ($\chi^2 = 358.79$, $p < 0.001$) with a higher proportion of the total activities occurring on beach A, with 71.5% of the emergences ($n = 176$).

Figures 8 and 9 show the spatial distribution of the successful nesting emergences and false crawls, respectively, during the survey period.

Table 2. Summary of green turtle (Chelonia mydas) nesting activity on each beach surveyed, including emergence density (number of successful nesting (SN) or false crawls (FC)/km) and beach length (km).

<table>
<thead>
<tr>
<th>Beach</th>
<th>Length (km)</th>
<th>SN / km</th>
<th>Number of SN</th>
<th>FC / km</th>
<th>Number of FC</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2.66</td>
<td>46.6</td>
<td>124</td>
<td>19.5</td>
<td>52</td>
</tr>
<tr>
<td>B</td>
<td>0.90</td>
<td>10.0</td>
<td>9</td>
<td>2.2</td>
<td>2</td>
</tr>
<tr>
<td>C</td>
<td>2.35</td>
<td>2.9</td>
<td>7</td>
<td>0.9</td>
<td>2</td>
</tr>
<tr>
<td>D</td>
<td>4.26</td>
<td>3.5</td>
<td>15</td>
<td>0.7</td>
<td>3</td>
</tr>
<tr>
<td>E</td>
<td>1.95</td>
<td>10.3</td>
<td>20</td>
<td>6.2</td>
<td>12</td>
</tr>
</tbody>
</table>
Fig. 8 – Distribution of successful green turtle (Chelonia mydas) nesting emergences on João Vieira Island during the surveys, highlighting beach A, with highest nest density.
Fig. 9 – Distribution of green turtle (*Chelonia mydas*) false crawls on João Vieira Island during the surveys, highlighting beach A, with highest false crawl density.
Sub-humid forest is the most representative terrestrial habitat facing the shores of the whole island (43.5% of all habitat types) (Table 3).

<table>
<thead>
<tr>
<th>Beach</th>
<th>Herbaceous</th>
<th>Shrubland</th>
<th>Forest</th>
<th>Cliffs</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>50.4</td>
<td>49.6</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>22.2</td>
<td>-</td>
<td>77.8</td>
<td>-</td>
</tr>
<tr>
<td>C</td>
<td>12.8</td>
<td>40.4</td>
<td>46.8</td>
<td>-</td>
</tr>
<tr>
<td>D</td>
<td>-</td>
<td>22.8</td>
<td>47.4</td>
<td>29.8</td>
</tr>
<tr>
<td>E</td>
<td>-</td>
<td>-</td>
<td>74.4</td>
<td>25.6</td>
</tr>
<tr>
<td>TOTAL</td>
<td>15.2</td>
<td>26.7</td>
<td>43.5</td>
<td>14.6</td>
</tr>
</tbody>
</table>

The nesting activity recorded in the different habitats can be seen in Table 4. The distribution of nesting activities was not random ($\chi^2 = 143.15, p < 0.001$), showing a higher number of emergences on herbaceous areas.

We found significant differences in the proportion of successful nesting events and false crawls in the different habitats ($\chi^2 = 22.45, p < 0.001$). This was evident mainly in herbaceous areas where 87.6% ($n = 78$) were successful nesting events, while in the shrubland represented 56.1% ($n = 55$) and in the forest 69.6% ($n = 39$). Also it should be noted the high number of false crawls in shrubland (60.6% of the total, $n = 71$), mainly in areas adjacent to herbaceous (Fig. 9).

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Beach Length (km)</th>
<th>SN / km</th>
<th>Number of SN</th>
<th>FC / km</th>
<th>Number of FC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herbaceous</td>
<td>1.84</td>
<td>42.4</td>
<td>78</td>
<td>6.0</td>
<td>11</td>
</tr>
<tr>
<td>Shrubland</td>
<td>3.24</td>
<td>17.0</td>
<td>55</td>
<td>13.3</td>
<td>43</td>
</tr>
<tr>
<td>Forest</td>
<td>5.27</td>
<td>7.4</td>
<td>39</td>
<td>3.2</td>
<td>17</td>
</tr>
<tr>
<td>Cliffs</td>
<td>1.77</td>
<td>1.7</td>
<td>3</td>
<td>0.0</td>
<td>0</td>
</tr>
</tbody>
</table>

Evaluation of habitat features showed that these varied greatly among the different beaches and habitat types as evidenced in Tables 5 and 6, respectively.
Table 5. Differences between habitat features in the different beaches surveyed on this study. Kruskal-Wallis ($H$) test was used to analyse all features, except for sand colour where Pearson chi-squared ($\chi^2$) test was used.

<table>
<thead>
<tr>
<th>Habitat features</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>df</th>
<th>Test</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bathymetry (km)</td>
<td>1.29</td>
<td>0.4</td>
<td>0.9</td>
<td>0.04</td>
<td>1.29</td>
<td>0.24</td>
<td>0.55</td>
<td>0.4</td>
</tr>
<tr>
<td>Distance highest spring tide line to vegetation (m)</td>
<td>6.85</td>
<td>11.9</td>
<td>0</td>
<td>0</td>
<td>0.79</td>
<td>3.08</td>
<td>0.22</td>
<td>1.15</td>
</tr>
<tr>
<td>Vegetation height (m)</td>
<td>5.28</td>
<td>2.9</td>
<td>8.8</td>
<td>1.56</td>
<td>5.6</td>
<td>3.15</td>
<td>7.6</td>
<td>4.5</td>
</tr>
<tr>
<td>Cliff height (m)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3.2</td>
<td>2.9</td>
</tr>
<tr>
<td>Ghost crabs (number of burrows)</td>
<td>26.2</td>
<td>25.4</td>
<td>0.56</td>
<td>1.1</td>
<td>7.2</td>
<td>11.6</td>
<td>3.3</td>
<td>5.1</td>
</tr>
<tr>
<td>Beach slope (%)</td>
<td>2.5</td>
<td>0.13</td>
<td>3.05</td>
<td>0.0</td>
<td>2.78</td>
<td>0.18</td>
<td>3.43</td>
<td>0.7</td>
</tr>
<tr>
<td>Sand albedo (%)</td>
<td>21.2</td>
<td>2.8</td>
<td>18.6</td>
<td>1.9</td>
<td>21.6</td>
<td>0.83</td>
<td>14.3</td>
<td>3.6</td>
</tr>
<tr>
<td>Sand colour</td>
<td>6.41</td>
<td>1.15</td>
<td>5.0</td>
<td>0.0</td>
<td>7.0</td>
<td>0.0</td>
<td>4.81</td>
<td>0.79</td>
</tr>
<tr>
<td>Sand grain size (µm)</td>
<td>67.3</td>
<td>2.3</td>
<td>138.6</td>
<td>74.6</td>
<td>131.7</td>
<td>0.53</td>
<td>94.4</td>
<td>13.7</td>
</tr>
<tr>
<td>Sand pH</td>
<td>6.15</td>
<td>0.4</td>
<td>6.67</td>
<td>0.5</td>
<td>6.0</td>
<td>0.0</td>
<td>6.33</td>
<td>0.48</td>
</tr>
</tbody>
</table>
Table 6. Differences between habitat features in each of the habitat types identified during this study. Kruskal-Wallis ($H$) test was used to analyse all features, except for: sand colour (Pearson chi-squared ($\chi^2$) test), and bathymetry, vegetation height and sand albedo (one-way ANOVA($F$)).

<table>
<thead>
<tr>
<th>Habitat features</th>
<th>Herbaceous</th>
<th>Shrubland</th>
<th>Forest</th>
<th>Cliffs or dunes</th>
<th>df</th>
<th>Test</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bathymetry (km)</td>
<td>1.4 ± 0.4</td>
<td>0.9 ± 0.4</td>
<td>1.0 ± 0.4</td>
<td>0.5 ± 0.2</td>
<td>3, 115</td>
<td>14.76</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Distance highest spring tide line to vegetation (m)</td>
<td>14.3 ± 13.4</td>
<td>0.16 ± 1.1</td>
<td>0.2 ± 0.8</td>
<td>0 ± 0.0</td>
<td>3</td>
<td>53.96</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Vegetation height (m)</td>
<td>5.0 ± 2.4</td>
<td>4.0 ± 2.4</td>
<td>9.9 ± 3.2</td>
<td>9.2 ± 3.3</td>
<td>3, 115</td>
<td>35.02</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Cliff height (m)</td>
<td>0 ± 0</td>
<td>1.5 ± 0.71</td>
<td>1.25 ± 0.35</td>
<td>4.1 ± 2.9</td>
<td>3</td>
<td>88.92</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Ghost crabs (number of burrows)</td>
<td>19.6 ± 19.0</td>
<td>15.6 ± 23.2</td>
<td>2.6 ± 4.7</td>
<td>2.3 ± 5.3</td>
<td>3</td>
<td>32.70</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Beach slope (º)</td>
<td>2.5 ± 0.2</td>
<td>2.9 ± 0.6</td>
<td>2.9 ± 0.4</td>
<td>3.3 ± 0.8</td>
<td>3</td>
<td>13.59</td>
<td>0.004</td>
</tr>
<tr>
<td>Sand colour</td>
<td>6.36 ± 1.3</td>
<td>6.05 ± 1.23</td>
<td>5.82 ± 0.9</td>
<td>4.13 ± 0.4</td>
<td>9</td>
<td>71.61</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Sand albedo (%)</td>
<td>21.4 ± 3.1</td>
<td>19.4 ± 3.9</td>
<td>16.2 ± 4.1</td>
<td>12.4 ± 3.9</td>
<td>3, 105</td>
<td>13.84</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Sand grain size (µm)</td>
<td>70.9 ± 17.6</td>
<td>95.9 ± 26.5</td>
<td>118.3 ± 34.7</td>
<td>80.8 ± 10.0</td>
<td>3</td>
<td>37.81</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Sand pH</td>
<td>6.1 ± 0.3</td>
<td>6.2 ± 0.4</td>
<td>6.2 ± 0.4</td>
<td>6.6 ± 0.5</td>
<td>3</td>
<td>10.74</td>
<td>0.013</td>
</tr>
</tbody>
</table>
3.4 Spatial distribution of nests

To elucidate the patterns of nest distribution on the beach, we divided the beach from the sea to the supra-littoral vegetation into three distinct zones: open sand; border (area between open sand and vegetation, usually the limit of the highest spring tide); and vegetation.

The distribution of nests in the three zones varied notably. Most of nests were found in the vegetation (49.1%, \(n = 86\)), comparatively with the border (34.9%, \(n = 61\)) and the open sand (16%, \(n = 28\)). However, the majority of the nests found in the vegetation were located within 2.98 m of the border (Fig. 10a).

The nest site selection in regards to the distance from the sea was significantly related to the tide cycles (\(\chi^2 = 10.41, p = 0.006\)), with more nests laid on the open sand during a neap tide (78.6%, \(n = 22\)) when compared with a spring tide (21.4%, \(n = 6\)) (Fig. 10b). Spring high tides were typically observed during full and new moons and neap tides during the last quarter of the moon.

![Graph a](image)

**Fig. 10 – a.** Relative frequency distribution of the distance (m) between green turtle (*Chelonia mydas*) nest sites and the highest spring tide line (HSTL): < 0 – open sand; 0 – border; > 0 - vegetation; **b.** Distribution of nests in different zones along the beach profile in relation to tidal cycle.

3.5 Habitat features at nest location

To further understand the habitat preferences of green turtles, a number of habitat features were also analysed at the nest location. We compared these features at regular points that characterize the whole island (see 3.3) as well at the location of each type of emergence (false crawls or successful nesting). Results are presented in Table 7.
Table 7 - Summary of the habitat features and differences between control location and those where each type of green turtle (*Chelonia mydas*) emergence was recorded. RP – regular points; SN – successful nesting and FC – false crawls. Kruskal-Wallis test was used to analyse all features, except for: sand colour (Pearson chi-squared test), and vegetation height, sand grain size and sand albedo (one-way ANOVA). Type of record in the same habitat feature that do not share subscripts (a or b) differ at p < 0.05 level of significance in the post-hoc Tukey HSD comparison.

<table>
<thead>
<tr>
<th>Habitat feature</th>
<th>Sample Size</th>
<th>Type</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>df</th>
<th>Test</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bathymetry (km)</td>
<td></td>
<td>SN a</td>
<td>175</td>
<td>1.13</td>
<td>0.43</td>
<td>0.25 – 1.85</td>
<td>2</td>
<td>18.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FC b</td>
<td>71</td>
<td>0.98</td>
<td>0.35</td>
<td>0.25 – 1.80</td>
<td>2</td>
<td>18.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RP b</td>
<td>119</td>
<td>0.92</td>
<td>0.47</td>
<td>0.24 – 1.85</td>
<td>2</td>
<td>18.3</td>
</tr>
<tr>
<td>Beach Slope (degrees)</td>
<td></td>
<td>SN a</td>
<td>175</td>
<td>2.61</td>
<td>0.35</td>
<td>2.3 – 4.1</td>
<td>2</td>
<td>44.79</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FC a</td>
<td>71</td>
<td>2.6</td>
<td>0.3</td>
<td>2.3 – 3.6</td>
<td>2</td>
<td>44.79</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RP b</td>
<td>114</td>
<td>2.93</td>
<td>0.54</td>
<td>1.64 – 4.31</td>
<td>2</td>
<td>44.79</td>
</tr>
<tr>
<td>Vegetation Height (m)</td>
<td></td>
<td>SN a</td>
<td>175</td>
<td>4.85</td>
<td>3.51</td>
<td>0.6 – 20</td>
<td>2, 362</td>
<td>16.91</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FC a</td>
<td>71</td>
<td>4.99</td>
<td>4.08</td>
<td>1 – 18</td>
<td>2</td>
<td>16.91</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RP b</td>
<td>119</td>
<td>7.34</td>
<td>3.93</td>
<td>2 – 20</td>
<td>2</td>
<td>16.91</td>
</tr>
<tr>
<td>Distance HSTL to vegetation (m)</td>
<td></td>
<td>SN a</td>
<td>175</td>
<td>5.12</td>
<td>8.04</td>
<td>-3 – 33</td>
<td>2</td>
<td>36.66</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FC a</td>
<td>71</td>
<td>1.28</td>
<td>4.1</td>
<td>0 – 25</td>
<td>2</td>
<td>36.66</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RP b</td>
<td>119</td>
<td>1.81</td>
<td>6.43</td>
<td>-2 – 50</td>
<td>2</td>
<td>36.66</td>
</tr>
<tr>
<td>Cliff height (m)</td>
<td></td>
<td>SN a</td>
<td>3</td>
<td>2.07</td>
<td>1.68</td>
<td>1 – 4</td>
<td>2</td>
<td>35.64</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FC a</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>35.64</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RP b</td>
<td>21</td>
<td>3.56</td>
<td>2.81</td>
<td>0.5 – 10</td>
<td>2</td>
<td>35.64</td>
</tr>
<tr>
<td>Sand grain size (µm)</td>
<td></td>
<td>SN a</td>
<td>175</td>
<td>82.35</td>
<td>29.58</td>
<td>64 – 217</td>
<td>2, 352</td>
<td>15.65</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FC a</td>
<td>71</td>
<td>81.79</td>
<td>26.63</td>
<td>64 – 217</td>
<td>2, 352</td>
<td>15.65</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RP b</td>
<td>109</td>
<td>101.66</td>
<td>33.37</td>
<td>64 – 217</td>
<td>2, 352</td>
<td>15.65</td>
</tr>
<tr>
<td>Sand colour</td>
<td></td>
<td>SN a</td>
<td>175</td>
<td>6.32</td>
<td>1.08</td>
<td>3 – 7</td>
<td>8</td>
<td>26.91</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FC ab</td>
<td>71</td>
<td>6.21</td>
<td>1.12</td>
<td>3 – 7</td>
<td>8</td>
<td>26.91</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RP b</td>
<td>109</td>
<td>5.84</td>
<td>1.15</td>
<td>4 – 7</td>
<td>8</td>
<td>26.91</td>
</tr>
<tr>
<td>Sand Albedo (%)</td>
<td></td>
<td>SN</td>
<td>175</td>
<td>18.91</td>
<td>4.36</td>
<td>2 – 25</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>FC</td>
<td>71</td>
<td>18.69</td>
<td>4.42</td>
<td>2 – 25</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>RP</td>
<td>109</td>
<td>17.67</td>
<td>4.56</td>
<td>9 – 25</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>Sand pH</td>
<td></td>
<td>SN a</td>
<td>175</td>
<td>6.1</td>
<td>0.33</td>
<td>4 – 7</td>
<td>2</td>
<td>7.53</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FC ab</td>
<td>71</td>
<td>6.1</td>
<td>0.42</td>
<td>4 – 7</td>
<td>2</td>
<td>7.53</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RP b</td>
<td>109</td>
<td>6.2</td>
<td>0.40</td>
<td>6 – 7</td>
<td>2</td>
<td>7.53</td>
</tr>
<tr>
<td>Ghost crabs (number of burrows)</td>
<td></td>
<td>SN a</td>
<td>153</td>
<td>17.42</td>
<td>17.35</td>
<td>0 – 76</td>
<td>2</td>
<td>38.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FC b</td>
<td>63</td>
<td>11.75</td>
<td>12.62</td>
<td>0 – 51</td>
<td>2</td>
<td>38.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RP b</td>
<td>119</td>
<td>8.66</td>
<td>16.53</td>
<td>0 – 87</td>
<td>2</td>
<td>38.4</td>
</tr>
</tbody>
</table>
There were significant differences between the features of the location where the females emerged, and those of the regular points, with the exception of sand albedo ($p > 0.05$) (Table 6). Results show that nest site selection is related to some of the habitat features, such as bathymetry, distance from HSTL to vegetation and in the number of ghost crabs burrows, as seen in Table 6 in the post-hoc Tukey HSD comparison. On the nest sites the mean distance from the coast to the 10 m isobath (mean = 1.13 km), the distance from HSTL to vegetation (mean = 5.12 m) and the number of ghost crabs burrows (mean = 17.4) was always higher than on false crawls sites or on the regular points.

3.6 Nest predation

3.6.1 Documented nest predation through video cameras

The video cameras revealed that monitor lizards were the only species predating on green turtle nests (100%, $n = 74$; Fig. 11). Predation rate (eggs/nest/day) varied greatly (mean = 14.6, SD = 24.2, range = 0 – 101), and took place mainly at daytime, with only 4 of the nests with evidence of night predation (it was not possible to identify the type of predator). There was a positive correlation ($r = 0.607, n = 74, p < 0.001$; Fig. 12) between the number of eggs being predated recorded on video and number of predated eggs counted during the daily surveys (mean = 5.97, SD = 10.18, range = 0 – 48). When analysing only nests where at least one egg was predated according to the video cameras, there was still a positive correlation with the number of predated eggs per nest counted during the daily surveys ($r = 0.368, n = 30, p = 0.046$).

Fig. 11 – a. Monitor lizard found predating on a green turtle (*Chelonia mydas*) nest; b. Green turtle (*Chelonia mydas*) nest with evidence of predation by monitor lizards.
3.6.2 Predation parameters through daily observations

Data collected during the daily surveys on João Vieira Island, showed that monitor lizards preyed on 76% of the marked nests ($n = 175$). The mean overall number of predated eggs per nest identified during the daily surveys was of 30.6 (SD = 17.4, range = 1 – 93, $n = 133$). The majority of the nest predation events occurred within the first days following laying (Fig. 13). Estimated daily predation risk (predate/monitored) was higher for freshly laid nests and declined with nest age (Fig. 14).
Fig. 14 – Estimated daily predation risk during the 10 days monitoring of each nest. For example, 45% of the nests monitored on the day 2 following laying and that still had eggs, were predated on that same day.

### 3.6.3 Comparison among beaches and habitats

To better understand the predation rates among beaches and taking into the account the low number of nests in some of the beaches we grouped them according to nest density, as follows: A – high density; B and E – intermediate density; and C and D – low density beaches.

Predation rates did not differed significantly between beaches ($\chi^2 = 3.632$, $p = 0.163$; Table 8). The same was found when comparing predation rates between habitats, where no differences were found ($\chi^2 = 2.931$, $p = 0.231$; Table 9). The habitat “cliffs” was excluded from this analysis since the sample size was too small ($n = 3$).

<table>
<thead>
<tr>
<th>Table 8. Percentage of predated nests on each beach.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beaches</td>
</tr>
<tr>
<td>A</td>
</tr>
<tr>
<td>B</td>
</tr>
<tr>
<td>C</td>
</tr>
<tr>
<td>D</td>
</tr>
<tr>
<td>E</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 9. Percentage of predated nests on each type of habitat.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Habitat</td>
</tr>
<tr>
<td>Herbaceous</td>
</tr>
<tr>
<td>Shrubland</td>
</tr>
<tr>
<td>Forest</td>
</tr>
<tr>
<td>Cliff</td>
</tr>
</tbody>
</table>
Furthermore, there were also no differences on the number of predated eggs per nest in the different beaches ($F_{4, 128} = 0.703, p = 0.591$), with the average number of predated eggs always quite similar in the different beaches (Table 10).

However, the number of predated eggs per nest differed significantly between habitats ($F_{2, 128} = 5.004, p = 0.008$), with higher mean number of predated eggs in nests located in herbaceous areas (Table 11). The habitat “cliffs” was excluded from this analysis since the sample size was too small ($n = 3$).

<table>
<thead>
<tr>
<th>Beach</th>
<th>Predated eggs per nest</th>
<th>mean</th>
<th>SD</th>
<th>range</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>99</td>
<td>30.8</td>
<td>17.3</td>
<td>1 – 93</td>
</tr>
<tr>
<td>B</td>
<td>8</td>
<td>33.1</td>
<td>5.1</td>
<td>11 – 54</td>
</tr>
<tr>
<td>C</td>
<td>3</td>
<td>21.7</td>
<td>6.2</td>
<td>10 – 31</td>
</tr>
<tr>
<td>D</td>
<td>11</td>
<td>24.6</td>
<td>4.8</td>
<td>3 – 52</td>
</tr>
<tr>
<td>E</td>
<td>12</td>
<td>30.6</td>
<td>6.5</td>
<td>8 – 80</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Predated eggs per nest</th>
<th>mean</th>
<th>SD</th>
<th>range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herbaceous</td>
<td>60</td>
<td>35.2</td>
<td>19.3</td>
<td>3 – 93</td>
</tr>
<tr>
<td>Shrubland</td>
<td>45</td>
<td>24.6</td>
<td>16.9</td>
<td>1 – 61</td>
</tr>
<tr>
<td>Forest</td>
<td>26</td>
<td>30.7</td>
<td>17.2</td>
<td>5 – 80</td>
</tr>
<tr>
<td>Cliff</td>
<td>2</td>
<td>25.0</td>
<td>15.1</td>
<td>13 – 37</td>
</tr>
</tbody>
</table>

3.6.4 Comparison with Poilão Island

No evidence of predation, or of predation attempts were found in any of the 37 nests marked for the purposes of this specific study on Poilão Island. These results differed significantly ($\chi^2_{1} = 75.46, p < 0.001$) from the predation rates found on João Vieira Island, where monitor lizards predated on 76% of the nests ($n = 175$).
4. DISCUSSION

Nesting habitat preferences

The study of the nest distribution on the island of João Vieira revealed that green turtles do select particular nesting sites and that this is not a process that occurs randomly along the nesting beaches.

The differences found in the emergence densities on the different beaches could have resulted not from a preference by green turtles for a particular beach, but from a variation in the availability of a suitable nesting habitat between beaches. In fact, all beaches differed significantly in all environmental characteristics measured, but the preference for beach A suggests that what seems to influence green turtles to emerge at that particular site along the whole island is the existence of a substantial area of open, low-height beachfront vegetation (herbaceous), where green turtles can dig their nests without obstacles. In fact, the nesting densities were higher in herbaceous habitats areas; furthermore most of the emergences that occurred on this habitat resulted in a successful nest, whereas in other habitats such as shrubland and forest the proportion of false crawls was higher, which means that these habitat types may result in fewer suitable sites for nesting.

One of the most interesting outcomes of this study concerns the analysis of the distribution of false crawls along the nesting beaches, an approach not normally analysed in detail by other authors (Provancha and Ehrhart 1987; Mazaris et al 2006; Chen et al. 2007; Ficetola 2007). A large ratio of false crawls/successful nesting events on a given stretch of beach may indicate a constant source of disturbance in the vicinity and/or that the females are selecting nests sites mostly after an initial exploratory emergence (Provancha and Ehrhart 1987). Many false crawls were observed on shrubland, composed mainly of dense tall grasses and bushes, and where the highest spring tide line usually reaches the vegetation limit. Particularly, the emergences that resulted in a false crawl were mainly found in stretches of this shrubland habitat type adjacent to the herbaceous habitats (see Fig.7), which may indicate that in fact green turtles are looking for such open beachfront vegetation of low-height.

We also found a higher number of false crawls during the full moon. The lunar phase may affect sea turtles vision as well as the visibility of the nesting beach (Law et al. 2010). On clear nights when the moon is full, visibility may be greater and the presence of shrubland, trees or cliffs, may discourage turtles from nesting. A slight decreasing number
of emergences from full moon to last quarter and new moon were also observed, but such
differences are very unlikely to be biologically significant. As the peak nesting for green
turtles occurs between August and September (Catry et al. 2009) and this study occurred
during the month of September, the number of emergences would normally be expected to
decrease with time after this nesting peak. The lunar phase appears to have a discernible
effect on green turtles nesting activity in João Vieira Island; however more detailed data
throughout a whole season may reveal different results.

A number of habitat features were assessed in João Vieira to further understand to
what extent these may explain the nesting habitat preferences of green turtles. Some of the
habitat features analysed were significantly different on the sites where green turtles
emerged when compared with the remainder of the island, such as beach slope and
vegetation height, suggesting that these features may influence sea turtles to arrive on the
beach independently of the outcome of the nesting attempt.

**Beach slope** This physical factor has been shown to play an important role in nest
site selection of sea turtles (Mortimer 1995; Wood and Bjorndal 2000; Cuevas et al. 2010);
this study showed that green turtles tended to emerge on beaches with gentle slopes.
Contrary to our results, Mortimer (1995) and Cuevas et al. (2010) reported that green
turtles choose to nest on beaches with slightly steep slopes, which may suggest that beach
slope is not a determinant feature for nest site selection of green turtles in João Vieira.

**Vegetation height** We found that green turtles tended to emerge in areas with
low vegetation height (< 5 m), suggesting that they may be using the vegetation height at
the upper part of the beach as a cue to evaluate the presence of a certain type of habitat or
as an indication that the area is not suitable for nesting (Hays and Speakman 1993; Mazaris
et al. 2006).

The above habitat features may explain what cues green turtles use to access the
beach at João Vieira but not the outcome of the nesting attempts. When the false crawls
sites were different from the nesting sites, then that would suggest that green turtles have a
finely tuned ability to use certain habitat features to select unique patches for oviposition.

**Offshore approach** Our results showed that green turtles tended to nest on
beaches with shallower offshore approaches (higher distances from the coast to the 10 m
isobath). These results were different from those of other studies, such as those on
Ascension Island, where green turtles seem to prefer the deepest approach to the beach
(Hays et al. 1995; Mortimer 1995). In addition, we found that for example beach C is also
characterized by shallow offshore approaches but had a lower nesting density, and therefore the depth of offshore entrances does not seem to be determinant for the nest site selection of green turtles on João Vieira. Furthermore, green turtles tended to emerge on beaches with an accessible offshore approach, relatively free of rocky reefs, which was consistent with previous studies (Mortimer 1995). However, all reefs at João Vieira are low-lying and covered by water during high tides, which allowed some turtles to successfully emerge and eventually find a suitable place to nest in some areas with rocky reefs, such as observed in the northeast of the island, on the very extreme of beach D with E (see Fig. 6 and 7).

*Crab burrows* Ghost crabs (*Ocypode cursor*) have been previously documented as a predator of sea turtle nests (Ali and Ibrahim 2002; Catry et al. 2002, 2009; Varo-Cruz 2010) and hatchlings (Glen et al. 2005; Tomillo et al. 2010; Rebelo et al. 2012). Despite documented predation of turtle eggs on other beaches, and their burrowing habits around turtle nests, ghost crabs at João Vieira did not seem to be linked to direct destruction of sea turtle eggs. However, their predatory role may be larger than our data indicates. Due to its particular behaviour and ecology, it is possible that we simply did not observed the predation that could have happened below the surface. Ghost crabs are known to make tunnels into the nest chamber and break open several eggs (Ali et al. 2007). Individuals usually build their burrows on open sand above the high tide line along a 15 m wide band (Tureli et al. 2009). This pattern is consistent with the differences in the distribution of the number of ghost crab burrows found along the island of João Vieira, with low numbers of ghost crabs on areas where the highest spring tide line practically reaches the vegetation. The high number of ghost crabs associated with the high number of nests may not only be related to the actual characteristics of the environment, but also with the availability of food, since ghost crabs could eventually be feeding on green turtle eggs. However, if ghost crabs in fact predated on some of the nests, this would be easily detected since eggshells could be visible in the burrows or in the surrounding area (Barton and Roth 2008; Leighton et al. 2009). Since this was not observed, it is likely that predation by ghost crabs on green turtles nests on João Vieira may not be significant.

*Distance from HSTL to vegetation* The João Vieira Island is characterized by relatively narrow beaches, where the highest spring tide line practically reaches the edge of any type of vegetation and/or habitat. But it should be noted that in this study, the distance from the HSTL to the vegetation was measured only considering any dense vegetation with more than 0.6 m height, i.e. shrubland or forest. Thus, on beach A, the higher distances
from the HSTL to vegetation corresponded mainly to areas of herbaceous vegetation, the habitat preferred by green turtles to nest, suggesting that the distance from HSTL to the tall and dense vegetation is a determinant factor on nest site selection. This means that low-height vegetation areas located above the highest spring tide line offer more choices of conditions for nesting.

Green turtles in João Vieira nested more often in the vegetation and border zones than on the open sand, when compared other studies (Withmore and Dutton 1985, Wang and Cheng 1999, Turkozan et al. 2011). But in fact, open sand areas are relatively rare in João Vieira Island during spring tides. Nests found on the open sand were more frequently laid during the neap tides, when dry open sand is more available. However, during the high spring tides there is a greater likelihood of nest inundation and loss of these nests to erosion, although this has not been evaluated on our study. A female has only a limited ability to assess the actual nesting environment when selecting a nest site, and changes in the nesting environment over the 50 or so days of incubation may be unpredictable (Bjorndal and Bolten 1992). This environmental uncertainty and the inability of the female to assess the habitat and predict hatching success, may explain why some nests were placed in the open sand, especially during neap tides.

**Sand characteristics** Considering that the quality of the beach sand can strongly influence reproductive success (Mortimer 1990), one would expect turtles to use sand texture as criteria in nesting site selection. In this study there were differences in the sand features, such as pH, colour and mean grain size, between the sites where sea turtles emerged and the whole island, but on the other hand no differences were found between the nesting sites and the false crawls, suggesting that green turtles in João Vieira may be looking for a habitat type that is associated with certain sand features, rather than having a preference for a specific sand feature, which is in accordance with previous similar studies (Mortimer 1995; Garmestani et al. 2000). Perhaps other results could have been obtained if pH, sand colour and mean grain size were measured along the entire length of the monitoring area and in all nest sites.

Usually, studies on sea turtle nest site selection have been focused mainly on selected beaches with high nest densities, rather than whole islands or beaches, and on particular habitat features, such as the distance of nests to vegetation and to the high tide line (Horrocks and Scott 1991; Hays and Speakman 1993; Hays et al. 1995; Kamel and Mrosovsky 2004, 2006; Serafini et al. 2009; Turkozan et al. 2011). Our methodological
approach for evaluating preferential nesting habitats based on the type of vegetation is not normally found in the literature and has not been studied extensively (Hays and Speakman 1993; Wang and Cheng 1999; Kamel and Mrosovsky 2005; Mazaris et al. 2006; Chen et al. 2007; Ficetola 2007).

Overall, our results revealed that on João Vieira Island, green turtles selected nest sites with herbaceous vegetation located above the high tide line and exposed to the sun, and occasionally nested on shrubland or forest. This shrubland may act as a barrier for nesting green turtles (Hays et al. 1993), and while some turtles give up nesting when encountering shrubs, others eventually find a suitable place to nest right in front (above the HSTL) or under the shrubs in shaded areas, saving energy that would be lost on a false crawl. In general, green turtles may be looking for a site on the beach that is easy to dig and stable enough for nest construction. If the vegetation becomes too dense (such as in the forest), it will increase the compactness of the surface layer with numerous root systems and digging attempts could be more difficult (Wang and Cheng 1999; Chen et al. 2007). Therefore, soft and short root systems found on herbaceous habitats may help by binding the sand, facilitating the construction of the egg chambers without compromising the female ability to excavate the nest (Mortimer 1995; Wang and Cheng 1999). Furthermore, our results suggest that green turtles select nest sites that will decrease the chance of tidal inundation. As suggested by Hays et al. (1995) and Garmestani et al. (2000), female turtles may simply crawl a random distance beyond the last highest spring tide line and then lay their nests.

Nest predation in João Vieira Island

An important finding of this study was to evidence the severe predation rates that affect green turtle nests at João Vieira Island. Monitor lizards (*Varanus niloticus*) predated 76% of the marked nests, with the majority of nest predation events occurring within the first days following laying. Monitor lizards have been found to be a nest predator on many Australasian rookeries, where in some beaches they predated on approximately half of the nests while in others regions nest predation was rare (Blamires and Guinea 2003). Similarly to our study, many other beaches elsewhere also experienced substantial nest predation (e.g. ≥ 75%), but from other predators species, such as ghost crabs or mammalian carnivores (Brown and Macdonald 1995; Bain et al. 1997; Engeman et al. 2006; Ficetola 2008). Our results showed that on João Vieira Island, there is a high
predation risk and it seems evident that nest predation may be a limiting factor on hatchling production.

Nest predation by monitor lizards on João Vieira took place within the first days after oviposition, similarly to other studies (Leighton et al. 2009, 2011). In sea turtles, nest predation risk is related primarily with the possibility of the nests being detected (Leighton et al. 2009). Predators may use disturbance of sand by the nesting turtles and olfactory cues released by the buried eggs for nest detection (Leighton et al. 2009). Olfactory cues released by the buried eggs may remain available after surface cues have disappeared (Leighton et al. 2011), which may explain the gradual decline in nest predation frequency following oviposition. However, this decline is also normally expected after an initially high predation of the nests on the first days that decreases the number of available eggs inside the nests. In the present study nests were monitored only during the first 10 days after oviposition, so it was not possible to infer on predation rates during mid-incubation or near hatching.

Habitat structure can have important effects on the risk of predation on sea turtles nests (Kolbe and Janzen 2002; Leighton et al. 2008). Beach vegetation is likely to be an important predictor of nest predation risk for predators that prey almost exclusively on nests in or near vegetation and that use this vegetation as a refuge (Parris et al. 2002; Marchand and Litvaitis 2004; Wetterer et al. 2007). In our study there were no differences on the predation rates in the different habitat types, and therefore the location of the nests per se was not a significant predictor of predation risk, suggesting that monitor lizards were likely to detect and prey upon encountered nests on any area on the beach. This may be due to the reduced human occupation on the island and in the absence of predators of monitor lizards (like mammals) that could hunt them in open areas. However, the number of predated eggs per nest differed significantly between habitats, with higher mean number of predated eggs in nests located in herbaceous vegetation. This may be associated with the habitat itself, i.e. eggshells were more easily found on low-height herbaceous than on shrubs or dense forest.

Comparison with Poilão Island

No evidences of predation or predation attempts were found on Poilão, although another study revealed that there is some limited, very low scale predation of nests by monitor lizards there (Catry et al. 2010). These results differed drastically from the predation rates found on João Vieira, where monitor lizards predated on 76% of the nests.
These differences on the predation rates between both islands could be related to the fact that on Poilão Island, the overwhelming saturation of nests on the beach, resulting strewn egg debris from overlapped nesting, and higher availability of other, more readily available food items, may result in a low nest predation of sea turtles. The spatial aggregation of nests found on Poilão Island may also affect predation, by decreasing it through predator satiation. Eckrich and Owens (1995) compared predation rates on nests of solitary versus arribada nesters in olive ridley sea turtles (Lepidochelys olivacea) in Costa Rica during the first 24 hours after oviposition, and found higher mortality of solitary nests, concluding that mass nesting affords some reduction of per-nest mortality. This density-dependent predation could explain such differences found on both islands. Nevertheless, such discrepancy underlines the need of understanding predator foraging ecology for making accurate predictions about nest predation risk.

Conclusions and conservation implications

This study resulted on important findings about the habitat preferences of green turtles nesting on João Vieira as well as on the habitat features that may influence sea turtles emerging from the surf, ascending the beach, and finally nesting successfully. It also provided basic ecological information about the green turtles nesting process and on the nest predation risks for the species.

The nest distribution on the island of João Vieira revealed that green turtles have a strong preference for a substantial open low-height beachfront herbaceous vegetation exposed to the sun. The choice for these herbaceous areas may have major consequences for the reproductive fitness of these females in response to environmental or anthropogenic changes. This is particularly important in the context of current environmental changes and habitat destruction and alteration. Sea turtles have temperature-dependent sex determination, and an emerging threat is that of rapid global environmental change and resultant warming which could alter the thermal characteristics of sand on nesting beaches (Kamel and Mrosowski 2005). The preference for such sun-exposed areas may skew the sex ratio towards a higher production of females. Green turtle hatchling survival and offspring sex ratios on João Vieira are unknown and should be better addressed as well as the potential impacts of global warming. In addition, taking into account the importance of these areas of herbaceous vegetation, conservation efforts should go towards the preservation of these particular nesting sites from human activities, or alternatively,
towards the maintenance of such herbaceous habitats, should their substitution by shrubs or forest be suggested.

Green turtle nests on João Vieira Island experience a severe predation by monitor lizards (*Varanus niloticus*). Such high predation rates found can be a limiting factor on the reproductive success of these females. Nest protection could be an effective measure to prevent predation. Several techniques are used in other rookeries to protect sea turtle nests from predators, these include predator removal, either by trapping, using poisons or chemical repellents, smoothing over nests or the use of wire screens, flags or ultimately nest relocation (Marcovaldi and Laurent 1996; Ratnaswamy et al. 1997; Marcovaldi and Marcovaldi 1999; Longo et al. 2009). However, besides ethical and ecological implications associated with these strategies, conservation and monitoring efforts on this nesting site could raise resource constraints to wildlife managers that strongly depend on the availability of funding and workforce (Catry et al. 2010). Nevertheless, based on the results of this study, we suggest that certain aspects of nest predation on João Vieira Island require further investigation and refinement, including a good understanding of predator foraging ecology, the collection of more detailed data on the relative importance of predation during the entire incubation period and the impact of nest predation on the hatching success.

The enormous differences on the predation rates found between João Vieira and Poilão islands suggest that there is a strong phenomenon of density-dependent predation. The extremely high nest density occurring in Poilão Island may reduce per-nest predation rates due to predator satiation. Quantifying density-dependent processes could have important implications for a good understanding of the population dynamics.

Although João Vieira Island seems to have a relatively important number of green turtle nests, when the nest numbers are compared with other green turtle nesting sites in the Bijagós archipelago (see Catry et al. 2002, 2009, 2010), and considering that its nesting beaches suffer from both human and natural predation and most of the nests are lost, it is possible that this nesting site may not be particularly important to the overall green turtle population of the Bijagós archipelago. However, beyond its conservation status and seasonal human occupation, we do not know exactly the importance of João Vieira Island for the green turtles nesting there or the ecological role of these females on the whole population. Indeed, many other questions should be addressed to improve our knowledge.
on green turtles trends on João Vieira, for the design of a comprehensive management and conservation program. For instance, it would be interesting to know if the females that nest in João Vieira present nest site fidelity, or if they alternate among islands; and if they differ in any maternal traits such as size or condition, fecundity, egg mass or offspring size, fitness and sex ratio.

Finally, human predation is also a risk for sea turtles nesting on João Vieira Island, and although this was not addressed in our study, we are aware of the consumption of the nesting females by the few people that inhabit the island. Therefore, conservation and monitoring efforts on João Vieira Island could also provide an opportunity to carry out surveillance regarding other anthropogenic threats such as illegal take.


MUNSSELL, A.H. 1946. A Color Notation: An illustrated system defining all colors and their relations by measured scales of hue, value and chroma (15th ed.). Baltimore, Maryland: Munsell Color Co.


