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Green turtles on the Island of Cavalos (Guinea-Bissau). Abundance, nest success and experimental nest protection

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“An understanding of the natural world and what's in it is a source of not only a great curiosity but great fulfilment”.

Sir David Athenborough

Abstract:

Of the seven extant species of sea turtle in the world, six are currently threatened with extinction. Poaching and egg recollection are some of many threats faced by these animals and that can lead to a decrease of their population numbers. Because of that, there is a large international effort to the preservation of the remaining sea turtle species. One of the main focus of these programs is the protection of the nesting grounds, as it is on this phase of their life cycle that sea turtles are more easily accessible to both predators and conservation teams. Indeed, several studies point that the recovery of some sea turtle populations is due to the protection of their nesting grounds and to an increase on the proportion of eggs that manage to hatch.

The Bijagós archipelago, in Guinea-Bissau, holds one of the largest nesting colonies of the green turtle, *Chelonia mydas* (Linnaeus 1758) in the world. In the island of Poilão alone, thousands of females come ashore to nest each year. This small island is part of a marine protected area, the "Parque National Marinho João Vieira e Poilão" (PNMJVP), a set of 4 small islands and islets, sacred to the inhabitants of the nearby islands.

We aimed to shed some light on the green turtles nesting on the island of Cavalos, an island of the PNMJVP where so far, no scientific study was performed aimed at this species. We found that more than two thousand nests were laid in this island during the 2016 nesting season. Additionally, turtles preferred to nest in the island dunes, a pattern that was different from what was observed in the nearby island of João Vieira, where they rather use the herbaceous plains. This finding is interesting under a climate change perspective as all the islands of the PNMJVP are very low, and the nests built in the dunes are better protected from flooding.

As in Cavalos there is a significant number of sea turtle nests predated by nile monitors, *Varanus niloticus* (Linnaeus 1758), we tested three different nest protection techniques. We used scent and visual masks, as well a nest protection technique used in other areas of the world that consists in protecting the nests with metal or plastic mesh nets. All the techniques tested resulted in a reduction of the number of nests predated. This is an interesting result and with relevance to the sea turtle populations, as the net protection commonly used is relatively expensive to employ in a large scale. As such, the use of a scent mask may be a viable alternative, given that the lizards rely mostly on scent cues to identify potential prey; furthermore, this method is inexpensive and easy to apply.

Keywords: Nest protection; exotic species; predation cues; turtle eggs; varanid lizards

Resumo alargado:

Das sete espécies extantes de tartarugas marinhas, seis possuem actualmente um estatuto de ameaça. A caça de adultos e juvenis, a morte acidental por artes de pesca e a recolecção de ovos são algumas das muitas ameaças enfrentadas por estes animais e que podem levar ao decréscimo dos seus efectivos populacionais. Como tal, existe um esforço internacional para a preservação das várias espécies de tartaruga marinhas existentes e um dos grandes focos desses esforços são os locais de desova. É nesta altura que as tartarugas estão mais facilmente acessíveis tanto para predadores (naturais e introduzidos) como para equipas de conservação. De facto, vários estudos apontam que a recuperação de algumas populações de tartarugas se deve precisamente à protecção dos seus locais de desova e ao aumento da taxa de eclosão dos seus ovos.

A tartaruga verde, *Chelonia mydas* (Linnaeus, 1758) é uma das sete espécies de tartarugas marinhas existentes actualmente. Esta espécie tem o estatuto de ameaça "Em perigo" (EN) atribuído pela IUCN desde a sua primeira avaliação desta espécie em 1982. Esta tartaruga encontra-se presente em águas tropicais e subtropicais em todo o Mundo, mas embora possua inúmeros locais de desova em quase toda a sua área de distribuição, existem alguns locais onde se pode encontrar uma densidade muito elevada de tartarugas nidificantes. Um desses locais é o Parque Nacional Marinho João Vieira e Poilão (PNMJV), no arquipélago dos Bijagós, Guiné-Bissau onde podemos encontrar a terceira maior população de tartarugas verdes nidificantes do Oceano Atlântico e a maior população desta espécie na costa africana.

Este estudo foi realizado no PNMJVP, um parque que foi criado com o intuito de proteger as populações de tartaruga verde ali nidificantes. É neste parque que encontramos a ilha de Poilão, uma pequena ilha com apenas 50 ha, onde todos os anos milhares de tartarugas vêm desovar, onde a densidade de ninhos pode ser superior a 1 ninho por metro quadrado, com um total de ninhos que em anos de maior abundância ultrapassa os 30 000. Contudo, embora nesta ilha ocorram censos anuais da população de tartarugas nidificante, as restantes ilhas do PNMJVP encontram-se relativamente pouco estudadas.

O PNMJVP é composto por 4 ilhas, alguns ilhéus e bancos de areia e a água que as envolve, possuindo ao todo 450 km^2 de área. Dessas quatro ilhas, para além de Poilão, apenas na ilha de João Vieira foi quantificada a população nidificante de tartarugas, com um total estimado de 596 ninhos em 2011, bastante diferente dos mais de 30 000 ninhos estimados para Poilão no mesmo ano. Nas restantes ilhas (Cavalos e Meio), nunca foi feito um estudo científico direccionado às populações de tartarugas.

As ilhas do PNMJVP são sagradas para os Bijagós da ilha vizinha (Canhabaque), sendo propriedade tradicional de quatro aldeias (tabancas) da mesma. Embora as quatro ilhas sejam sagradas e desempenhem um papel fundamental no ritual de passagem à idade adulta praticado pelos bijagós (o "fanado"), existem normas de conduta diferentes entre as várias ilhas. Enquanto que em Poilão é proibido o derramamento de sangue e o corte da vegetação, essas regras relaxam nas outras ilhas. Em Cavalos já não existem regras contra o derramamento de sangue, embora não seja permitida a entrada na floresta a quem não passou ainda pelo ritual do "fanado". Finalmente, nas ilhas de João Vieira e Meio, é praticado "m'pam pam", uma prática de agricultura itinerante de arroz que envolve o uso de queimadas e o corte da vegetação nativa, intervalada por alguns anos (a duração do intervalo é variável) durante os quais na zona intervencionada existe crescimento de floresta secundária. Na ilha de Cavalos, existem porcos ferais, *Sus scrofa* (Linnaeus 1758), que se pensa terem sido introduzidos pelos nativos das ilhas vizinhas e cujo impacto na população de tartarugas é desconhecido.

No primeiro capítulo desta tese foi feita uma estimativa do número total de tartarugas que utilizaram a ilha de Cavalos como local de nidificação em 2016. Esse valor foi comparado com a intensidade de utilização das ilhas de João Vieira e Poilão, podendo-se assim determinar que a ilha de Cavalos tem uma importância intermédia entre João Vieira e Poilão, com mais de 2000 ninhos estimados para esse ano. Foi feita também uma análise da utilização das diferentes zonas da ilha e dos seus habitats. As tartarugas não utilizaram a ilha por igual, evitando a costa sul e concentrando os seus ninhos nas dunas da costa sudeste. O sucesso de nidificação em Cavalos foi aproximadamente metade do registado em João Vieira e em Poilão (cerca de 35% em Cavalos e 70% nas outras ilhas). Pensamos que essa diferença possa dever-se às características da costa de Cavalos, que em grande parte da sua extensão não apresenta habitat propício para a desova, visto que na maré alta o mar sobe até à floresta.

Para além de estudar as dinâmicas de desova na ilha, foi feita uma análise focada nos predadores dos ninhos de tartaruga. Em Cavalos, os varanos, *Varanus niloticus* (Linnaeus 1758) foram responsáveis por grande parte da predação, predando 30% dos ninhos monitorizados. Foi também registada predação por parte de caranguejos fantasma, *Ocypode cursor* (Linnaeus 1758) que predaram apenas 6% dos ninhos. Os porcos ferais, cujo impacto nos ninhos de tartaruga era desconhecido, não predaram nem perturbaram quaisquer ninhos, sendo que em 32 dias apenas foram encontrados 9 indícios de actividade de porcos na praia (pegadas e avistamentos). Conseguimos também determinar, através de uma regressão binomial, que a proximidade à vegetação aumenta a probabilidade de os ninhos serem predados por varanos.

No segundo capítulo desta tese, foi feito um estudo direccionado à predação dos ninhos pelos varanos. Foram testados 3 métodos de protecção de ninhos, um baseado numa máscara odorífera, outro baseado na camuflagem visual dos ninhos e por fim um método de protecção com redes, já com efeitos comprovados noutras praias de nidificação. Os três métodos de protecção resultaram numa redução do total de ninhos predados de 30% para aproximadamente metade. Contudo, essas diferenças não foram estatisticamente significativas, embora os "p-value" se encontrem muito próximos do limite de 0.05. Para além disso, foi feito um teste com 2 tipos de ninhos artificiais: no primeiro foram usados ovos verdadeiros de tartaruga de forma a deixar pistas odoríferas para os predadores de tartarugas, mas visualmente os "ninhos" foram camuflados de forma a não deixar pistas visuais. No segundo conjunto foi feito o oposto. Os "ninhos", embora não possuíssem ovos no seu interior, foram construídos de forma a terem o aspecto de ninhos verdadeiros, de maneira a providenciar apenas pistas visuais para os predadores. Os varanos foram capazes de detectar e predar os "ninhos" com ovos no seu interior, contudo não reagiram aos "ninhos" falsos sem ovos. Isto sugere que os varanos se baseiam principalmente no olfacto para detectar os ninhos. Considerando que os tratamentos de protecção de ninhos tiveram reduções similares na predação e visto que os varanos se baseiam principalmente no olfacto para a detecção de presas, o uso de uma máscara de cheiro parece ser um método a considerar na protecção de ninhos. Este resultado é importante pois a protecção de ninhos contra predadores naturais e introduzidos é uma tarefa morosa e dispendiosa quando se usam redes de metal, e o uso de máscaras de cheiro permite reduzir consideravelmente os custos e tempo envolvidos neste processo.

Esta foi a primeira vez que foi feito um estudo científico direccionado às tartarugas marinhas na ilha de Cavalos. Os resultados deste estudo permitem uma melhor compreensão da importância que o PNMJVP tem para as populações de tartarugas marinhas da Guiné-Bissau.

Palavras-chave: Protecção de ninhos; espécies exóticas; pistas de predação; ovos de tartaruga; lagartos varanos

Index:

List of tables:

List of figures:

Introduction:

Sea turtles biology:

Sea turtles are very long-lived animals with a long juvenile phase, after which mature females typically return to their natal beaches to nest (Lutz et al., 2003). The green turtle, *Chelonia mydas* (Linnaeus, 1758) is a sea turtle belonging to the family Cheloniidae. Like in all sea turtles, adult females return to the shore only to lay eggs, usually at the same beach they were born (Scott et al., 2012). The females dig nests in the sand, at a depth of more than fifty centimetres (Sönmez and Özdilek, 2011), where more than one hundred eggs can be laid at a time (Sönmez and Özdilek, 2011). During each breeding season, a female will lay on average five clutches, in a time range of two to three months (Fitzsimmons, 1998; Hamann et al., 2003). The eggs are laid during the nocturnal high tide, so that females are exposed for a period as short as possible (Lutz et al., 2003). As there is frequently a huge distance between its feeding and breeding areas, sea turtles do not reproduce every year, instead taking some years after a nesting season to prepare for the next reproduction (Hamann et al., 2003). The length of that break is variable as it is mostly dependent on the feeding opportunities the turtles find during those years (Hamann et al., 2003).

Survival of the eggs and hatchlings is very low even in natural conditions (Lutz et al., 2003). Several studies showed that an improvement in nest survival results in positive demographic trends for the local populations (Dutton et al., 2005; Seminoff, 2004) even when the global population trend is negative (Seminoff, 2004). Successful nesting thus emerges as an important factor to consider when trying to preserve sea turtles.

Sea turtles are widespread around all the tropical and even subtropical waters, with turtles nesting in the Atlantic, the Indian and the Pacific Oceans and even the Mediterranean Sea. However, although there are sea turtles nesting in almost every sand beach within their natural distribution, there are some places where sea turtles nest in unusually high densities. In those places, the turtles of the genus *Lepidochelys* can nest in a phenomenon called “arribada” in which hundreds of turtles come ashore in a very short period (Eckrich and Owens, 1995); in the other genus, the nesting activity can be more evenly spaced in a nesting season that can last for several months (Catry et al., 2002). Examples of high sea turtle nesting density sites in the Atlantic Ocean are the Florida peninsula or the islands of Cabo Verde, that maintain high densities of nesting loggerhead turtles, *Caretta caretta* (Linnaeus, 1758) (Turtle Foundation, 2017), and Tortuguero (Costa Rica) and Guiné Bissau for the green turtle, which are the first (Troëng and Rankin, 2005) and third (Catry et al., 2010) most important place for the green turtle in the Atlantic Ocean respectively.

Study area:

The Bijagós archipelago has long been identified as a hotspot for the green turtle, but until 1991, no scientific information was available on the nesting intensity at the archipelago (Fortes et al., 1998). Later, it was found that in the island of Poilão several thousands of sea turtles nest each year (Catry et al., 2002). This means that this small island is the most important nesting site for this turtle in all of Africa and the third most important nesting site in the Atlantic Ocean (Catry et al., 2009). Due to the huge importance that this place has to the world’s sea turtle populations, Poilão and the nearby islands

were converted in a protected area, the João Vieira and Poilão Marine National Park (PNMJVP) (Catry et al., 2002). The PNMJVP is composed by 4 islands, João Vieira, Cavalos, Meio, Poilão, and some islets and sand banks, as well as the sea around them, in a total area of 495 km^2 (Catry et al., 2010). The islands have a dense forest cover, comprised mainly of palm trees (*Elaeis guineensis*), but with some hardwoods as well. In the islands of João Vieira and Meio there is also a denser, secondary forest area, due to the slash and burn agriculture practiced periodically in those islands (Cuq, 2001). The islands are surrounded by shallow waters and there is a sand bank south of Cavalos that extends almost to the island of Meio, where the sea is never more than 10 meters deep (Cuq, 2001). The island of João Vieira is surrounded by deeper waters, up to 50 meters deep (Cuq, 2001).

It is believed that there is such high abundance of sea turtles in the island of Poilão not only because of it being so remote, but also because of the sacred role that island plays to the inhabitants of the nearby islands (Catry et al., 2010; IBAP, 2008). In Poilão, even the act of setting foot in the island is only allowed during specific rituals like the coming of age ceremony called "fanado". (IUCN, 2002). The island of Cavalos also plays an important role for the nearby islanders' religion; however, the rules there are not as strict as in Poilão (Catry et al., 2010). No scientific survey of sea turtles nesting activity was ever performed at Cavalos (IBAP, 2017). Due to the religious protection that island has, it is expected that the sea turtle populations there may have some relevance (Catry et al., 2010).

In the PNMJVP, turtles' nests face two main predatorial threats: a reptile, the nile monitor, *Varanus niloticus* (Linnaeus, 1758) and a crustacean, the ghost crab, *Ocypode cursor* (Linnaeus, 1758) (Catry et al., 2009). The lizards from the Varanid family are common sea turtles' nest predators all over the world (Blamires and Guinea, 2003; Lei and Booth, 2017; Shine, 1986). They have variable, site-specific predation rates, varying from almost 100 % (Cruce, 2009) to less than 5 % in areas where there is high nest density (Eckrich and Owens, 1995). The nile monitor is an active forager, relying on both scent and visual cues to detect a potential prey (Kaufman et al., 1996). They are generalist predators, adapting their diet to the different food sources available in their habitat (Losos and Greene, 1988). As most of the Varanids, the nile monitor is a highly intelligent animal, being able to learn new behaviours and memorize patterns with relative ease (Firth et al., 2003). This species is diurnal, with the activity peaking in mid-morning (Shine, 1986). Generally, nile monitors are only able to detect sea turtle nests during the first few days after oviposition, with the peak of predation occurring after just one or two days after the nest is built (Gonçalves et al., 2007; Leighton et al., 2009, 2011). The lizards take refuge in the vegetation (Shine, 1986) and can cover great distances when in search for profitable prey (Losos and Greene, 1988). In the Bijagós archipelago they are documented predators in all the islands studied so far, with estimated predation rates differing from island to island, ranging from more than 70% in the island of João Vieira (Ferreira, 2012) to just 3% in the island of Poilão (Catry et al., 2002).

Ghost crabs are also common predators in most sea turtle rookeries all over the world (Dodd and Kenneth, 1988). Their predation rates are also variable between each rookery, but, one of the greatest differences between these animals and the nile monitors is that their predation is not so strongly limited to the first few days after oviposition (Fowler, 1979). Indeed, the crabs predate more eggs in the first days after the nests are dug, but also have a smaller predation peak near the end of the hatching period and are reported to be able to predate nests during the entire incubation period (Fowler, 1979). Unlike the lizards, these animals are mostly nocturnal (Tureli et al., 2009) and build their burrows just a few meters above the high tide line (Ferreira, 2012; Strachan et al., 1999), in the same area chosen by most sea turtles to dig the nest. In the Bijagós archipelago the crabs are less important predators than the lizards (Catry et al., 2010). Although in Orango, during the 1992-1994 seasons, they predated 35.9

% of the nests, which was more than the lizards did during the same period (Catry et al., 2009), however, in Poilão, they were responsible for only 1% of predated nests (Catry et al., 2002) and in João Vieira there was no record of ghost crab predatorial activity (Ferreira, 2012).

At Cavalos, there is the added threat of the introduced feral pig, *Sus scrofa* (Linnaeus 1758) population that exists in that island. Feral pigs are omnivores and generalist predators (Cruz et al., 2005), known to be very disturbing in small insular ecosystems (Nogueira-Filho, 2009) and they can be turtle nest predators if the opportunity arises (Cruz et al., 2005; Roemer et al., 2001). In Cavalos so far, the impact of these pig in the turtle nests has never been quantified.

Nesting preferences:

Although some species like the loggerhead turtle do not seem to have any nesting preferences, choosing an apparently random nesting place in the beach, green turtles seem to have preferred nesting places (Hays et al., 1995). Usually, green turtle nests are found more often in elevated areas of the beach with low vegetation (Hays et al., 1995). Here nests can be safe from the sea water, since the flooding of a nest can destroy the entire clutch (Hays et al., 1995), without it being too vulnerable from vegetation dweller predators. This kind of behaviour is particularly noticeable in highly dynamic beaches, prone to erosion. Another reason for sea turtles to avoid using densely vegetated areas is that dense vegetation not only hinders the turtle movements, but their roots can wrap themselves around the eggs, causing them to abort or creating deformities in the embryos (Wyneken et al., 1988). Finally, the offshore approach to the beach seems to matter as well. Turtles tend to choose beaches with a steeper offshore approach so that they can minimize the distance they have to crawl until they reach their nesting habitat (Hays et al., 1995). In the Bijagós, a recent study has shown that at least in João Vieira, turtles seemed to prefer beaches with gentle offshore approaches (Ferreira, 2012); however, in that island, that characteristic is associated with their most frequent nesting habitat (Ferreira, 2012).

Current threats and management options:

Human population is rapidly expanding in the tropics (O'Neill et al., 2010). This means that there are more and more human settlements near nesting grounds, which increases their vulnerability to egg recollection. This threat is significantly serious in poor countries, where sea turtles and their eggs are a very cheap and abundant protein source (Catry et al., 2010). In some areas, the egg loss rate due to human predation can be almost 100% (Cruce, 2009). This is aggravated by the philopatric behaviour of sea turtles. Sea turtles, in most cases, return to the very beach in which they were born to breed (Scott et al., 2012); so, a disturbed place will be used by turtles that were born when that place was safe. Considering this, protecting and studying the current nesting grounds is a priority for sea turtle conservation and as such, an important part of conservation programs is focused on protecting the hatchlings and diminishing the number of eggs lost to both natural and human causes (Marcovaldi and Chaloupka, 2007; Turtle foundation, 2017).

There are several approaches on how to best protect a turtle nest. In places where there are human populations near important nesting beaches like Cabo Verde or some places in Brazil, usually significant human and financial resources are involved in patrolling the beaches and preventing humans from harvesting the eggs or damaging the nests (Marcovaldi and Chaloupka, 2007; Turtle foundation,

2017). When the main concern is not human recollection but predation from natural or introduced predators, conservation efforts focus in decreasing the ability of those predators to affect the nests (Barton and Roth, 2008; Engeman et al., 2002, 2003). This can be made in one of two ways: in some places where predator density is very high, culling of the most damaging species is often done (Engeman et al., 2002, 2003), but that may have negative consequences in the local ecosystem and does not always decrease overall predation rates (Barton and Roth, 2008). The alternative to this method is to reduce the predators' ability to detect or reach the nests. The use of a metal net over the nests was successful in reducing predation rates by some mammalian carnivores (Yerli et al., 1997), and more recently, some studies point that this technique is effective in decreasing predation rates by other taxa, like reptiles (Lei and Booth, 2017). However, based in the predator's ecology, it is possible that other, less time-consuming techniques than this can be used.

When building its nest, a turtle leaves several cues around it that are exploited by predators. Those cues can be visual, olfactory, tactile or a combination of two or more (Blamires et al., 2003; Oddie et al., 2015). Understanding which cues each predator uses can lead to more efficient nest protection techniques, optimized to the specific conditions of each site.

Objectives:

In the first chapter of this thesis, we analysed the abundance and distribution of green turtle nests on the island of Cavalos and compared our results to those of the other islands of João Vieira and Poilão Marine National Park. We also studied nest predation at Cavalos and the impact of the introduced feral pigs' population. In the second chapter we tested different nest protection techniques and made a preliminary analysis on the prey detection mechanisms used by the island's nile monitors.

This was the first time that a scientific study on the sea turtles of the island of Cavalos was performed.

Chapter 1: The green turtles of Cavalos (Bijagós, Guinea-Bissau): Nesting biology and nest predation in an uninhabited tropical island.

Abstract:

The Bijagós archipelago (Guinea-Bissau) holds one of the largest green turtle, *Chelonia mydas* (Linnaeus, 1758) nesting populations of the world. In the island of Poilão alone there are thousands of nests each year, with more than one nest per square meter in the nesting grounds. Poilão is subject of intensive monitoring since the year 2000; however, the role of several other islands of the archipelago has not been thoroughly investigated.

In this study we performed the first census on the green turtle nesting biology in the island of Cavalos. We then extrapolated the results to the entire nesting season so that we could compare the nesting intensity in Cavalos, João Veira and Poilão islands. We also identified the coastal areas where the highest nesting density could be found. We quantified the predatorial pressure by the two main predators of the archipelago: the nile monitors, *Varanus niloticus* (Linnaeus, 1758) and the ghost crabs, *Ocypode cursor* (Linnaeus, 1758) and measured the variables influencing predation by nile monitors. Finally, we made the first evaluation of the impact of the island's population of feral pigs, *Sus scrofa* (Linnaeus, 1758) on sea turtle nests.

We estimated a total of 2507 nests for the island of Cavalos during 2016 nesting season, making it second in importance to Poilão in the National Park. In Cavalos turtles nest mainly in high dunes and avoid using the Southern coast of the island.

Curiously, we have not seen any evidence of feral pigs disturbing turtle nests, with the only registered predators in Cavalos being the lizards and the crabs, although the last ones only predate a small portion of the nests. Finally, we found that not all nests are equally vulnerable to predation, with nests located nearer the island vegetation being the most vulnerable.

Key words: nile monitor; nest predation; Guinea.Bissau; nesting habitat; ghost crab; feral pigs

Introduction:

The nests of sea turtles face several threats. There are several biotic and abiotic factors that can reduce the viability of the embryos, preventing the eggs from successfully hatching. For instance, when the nests are built near vegetated areas, dense roots can wrap themselves around the eggs, killing the embryos or creating deformities in the hatchlings (Wyneken et al., 1988). Another common cause for egg destruction is nest flooding, that can kill the entire clutch (Hays et al., 1995) and can become a bigger problem in the near future, considering the predicted sea level rise. Female selection of appropriate nesting habitat can be vital to nest survival, as different habitats even if in the same beach will have different nest or hatchlings survival rates (Kamel and Mrosovsky, 2005). Indeed, in some populations some habitats are positively selected over others (Hays et al., 1995), with more vegetated areas being usually less desirable for the turtles (Hays et al., 1995). Besides this, sea turtle nests can be predated by almost all the predators that use the shore as a feeding ground, such as monitor lizards

(*Varanus* sp.) (Blamires et al., 2003) and crabs (Marco et al., 2015). Besides the "traditional" egg predators, some animals that are not usually associated with coastal environments, like foxes, *Vulpes vulpes* (Linnaeus, 1758) or wild pigs, are known to opportunistically use the eggs as a feeding resource (Cruz et al., 2005; Terli et al., 1997).

Although sea turtles may nest in almost every sand beach in the tropics and subtropics, there are some places where nesting occurs at higher density than others. In those beaches there can be thousands of females nesting each year. In the Atlantic Ocean, Florida and the islands of Cabo Verde have such types of nesting grounds for the loggerhead turtle, *Caretta caretta* (Linnaeus, 1758), (Casale and Tucker, 2005; Seminoff, 2004), and Guinea-Bissau for the green turtle. In Guinea-Bissau there is the third most important nesting place for this species in the Atlantic, with several thousand turtles nesting every year (Catry et al., 2009, 2010).

At Guinea-Bissau, the bulk of sea turtle nesting activity occurs in Parque Nacional Marinho João Vieira e Poilão (PNMJVP) (Catry et al., 2010), a marine national park comprising the islands of João Vieira archipelago and the sea around them, with a total area of 495 km^2 (Catry et al., 2010). These islands are sacred to the population of the broader Bijagós archipelago (IBAP, 2008), in which the PNMJVP is inserted. The sacred character of these islands may partially explain why it maintains such an abundance sea turtle population, comparing with the rest of the archipelago (Catry et al., 2010). It is forbidden to set foot on Cavalos and Poilão (two of the 4 main islands of the archipelago) except during some specific ceremonies and passage rites such as the "fanado" where young men pass from youth to older age (Cross, 2014). Additionally, the island with the highest number of sea turtles (Poilão), with an estimated total number of nests of more than 30000, which is equivalent to more than one nest per square meter (Catry et al., 2010) is also the most remote island of the PNMJVP. This island is by far the most studied. In fact, while Poilão is subject of an extensive monitoring of nesting activity every year since the beginning of this century (Catry et al., 2010) and has been subject to regular monitoring campaigns since 1994 (Catry et al., 2002), the other islands of the Park are not well studied. In João Vieira, it was only in 2011 that the first census was made (Ferreira, 2012) and in Cavalos and Meio no regular monitoring campaigns ever occurred (IBAP, 2017), so the real importance of these islands for the green turtle population is still unknow.

In all the islands, sea turtle eggs are predated by ghost crabs, *Ocypode cursor* (Linnaeus, 1758) and nile monitors, *Varanus niloticus* (Linnaeus, 1758) (Catry et al., 2010; Ferreira, 2012). Even after hatching, hatchlings are vulnerable to predation by the same and other opportunistic predators such as the palm-nut vulture, *Gypohierax angolensi*, (Gmelin, 1788) with predation of eggs and hatchlings registered in low quantities in João Vieira and with higher incidence (although still far from being regular prey) in Poilão (Carneiro et al., 2017). The nile monitor is by far the most important nest predator on these islands (Catry et al., 2010), predating up to 76% of the nests in João Vieira (Ferreira 2012), but only around 3% of the nests in Poilão (Catry et al., 2002). Besides natural predators, sporadically the sea turtle eggs and even adults are consumed by fisherman or during the religious activities occurring on the islands (Catry et al., 2010; IBAP, 2017). The low predatory impact by the ghost crab in PNMJVP is different from the rest of the Bijagós archipelago, where in Orango for instance, they were responsible for 35% of predation events during the 1992-1994 surveys (Catry et al., 2009).

A common cause for species declines in insular environments is the introduction of exotic animals (Drake et al., 2002). In the PNMJVP, there are records of the introduction of pigs on João

Vieira and Cavalos. This can present a problem as pigs are known to cause great damage in small isolated environments due to their extreme adaptability and generalist behaviour (Cruz et al., 2005; Roemer et al., 2001;). Despite the introduction of these animals having been documented for some time (Catry et al., 2010), there are no studies of the pigs' impacts on these islands.

With this study, we compared the nesting intensity of Cavalos with that on the other islands of the Park. We also studied the predatory impact of the different nest predators found in the island of Cavalos. Besides that, we studied which are the most important areas and habitats of the island for the sea turtles, and if there is a relation between habitat and susceptibility to predation by nile monitors. Finally, we documented the impact of the feral pig population on the sea turtle's nests.

Methodology:

Study site:

This research was conducted in Parque National Marinho João Vieira e Poilão, (PNMJVP), a protected area comprising 4 small islands in the south-east of the Bijagós archipelago, Guinea-Bissau. The Bijagós is a group of 88 islands and islets with a population of 34563 inhabitants according to the 2009 population census (Instituto Nacional de Estatística, 2009). Its climate is characterized by alternating dry (November to May) and wet (May to November) seasons with an annual rainfall of 1500 to 2000 mm (Catry et al., 2010). This archipelago is of continental origin as it originated from the flooding of the ancient river Geba delta, which resulted in the peculiarity of having mostly shallow waters and huge intertidal areas (95% of the sea surrounding the archipelago's islands is less than 30 meters deep (Rebelo and Catry, 2011)).

The islands of the PNMJVP are traditional property of the inhabitants of four "tabancas" (villages) from the nearby island of Canhabaque, whose inhabitants maintain religious beliefs that are closely related to these islands, which are sacred to them and used in some rituals (like the coming of age ritual called "fanado") (IUCN, 2002). The largest island of the PNMJVP is João Vieira (900 ha), followed by Meio (402 ha), Cavalos (210 ha) and Poilão (50 ha) (IUCN 2002). João Vieira is the only island with permanent settlers (a single family that runs a small resort comprising a few huts). Additionally, there are some temporary fishing encampments in João Vieira and to a lesser extent in Meio which in the last few years have shown some tendency to become more permanent (Catry et al., 2010), and a periodic (very roughly once every seven years) slash and burn rice agriculture ("m'pam-pam") that occurs in both Meio and João Vieira (IUCN, 2002). The "m'pam-pam" involves the migration of practically the entire village (a couple of hundreds of man, women and children) for the islands, from late May until rice harvesting by the end of the rainy season (October or November). That period coincides with the peak of the green turtle nesting season (Catry et al., 2002).

The island of Cavalos is mostly covered by a dense forest, comprised mainly of palm trees (*Elaeis guineensis*), but with some hardwoods as well (Cuq, 2001). In the islands of João Vieira and Meio there are areas of dense palm trees as well, but in some portions of these islands, we can find a denser, secondary forest area and some areas with exposed soil (Cuq, 2001), created due to the "m'pam-pam" (Catry et al., 2010). The islands are surrounded by shallow waters and there is a sand bank south of Cavalos that extends almost to the island of Meio, where the sea is never more than 10 meters deep. The island of João Vieira is surrounded by deeper waters, up to 50 meters deep (Cuq, 2001).

Field Methodology

Beach surveys:

Field work was conducted on the three less studied islands of the Park, João Veira, Meio and Cavalos, the last one being the main focus of this study. The survey periods in each island are depicted in Table 1.1

Table 1.1: Survey period for each island of the PNMJVP. Surveys were performed daily and covered all the island perimeter.

Island	Survey Period (dd/mm/yyyy)
Cavalos	06/08/2016 to 08/09/2106, 05/10/2016, 07/10/2016 and 10/10/2016*
Meio	10/08/2016, 25/08/2016 and 04/09/2016
João Vieira	11/09/2016 to 24/09/2016 and 03/10/2016 to 10/10/2016

*the last three days were not used for the estimate of total season nests, as using surveys of isolated days does not produce accurate estimates.

During the surveys, the whole length of the coast was scouted (13 km in João Vieira and 7 km in Cavalos) and all sea turtle emergences were recorded and classified as:

- Successful nest- when the turtle climbs the beach, lays its eggs and returns to the sea. Successful nests were verified for eggs using the same method the native bijagós islanders use to hunt for nests, using a stick to prod the sand in the suspected nesting spot to confirm if the sand had been recently dug. (figure 1.1). This was done carefully to minimize the risk of damaging the eggs;
- Nesting attempt- when the turtle climbs the beach and starts digging one or several nests, but abandons the beach without laying any eggs;
- False crawl- when the turtle climbs the beach, but just wanders around, returning to the water, not attempting to build a nest.

Figure 1.1: One of the Canhabaque inhabitants searching for the egg chamber in a recently dug green turtle nest. He prodded the nest with a stick to ascertain the consistency of the sand. When the sand was loose it meant the presence of a nest.

A total of 32 surveys were made in Cavalos. The survey team consisted of 4 people: myself, a technician from Instituto da Biodiversidade e das Áreas Protegidas (IBAP) and two inhabitants of the nearby island of Canhabaque. A total of 16 surveys were made on João Vieira. Surveys would start with the sunrise and last 4 or more hours, depending on the intensity of the activity of the night before. In João Vieira, surveys were usually conducted by only one person, with the occasional help from the park guards. In this island it was frequent to see some fisherman on the beaches and seldom signs of human predation of the nests. Because of that, successful nests were not verified as in Cavalos to avoid providing cues on their location. Successful nesting events were identified only by expert opinion.

In Cavalos we registered the habitat around the nest or the apex of the track (habitat categories depicted in table 1.2) and its coordinates. When the visits were not on consecutive days, we also registered the age of the track (fresh – from the previous night, or old – before that). We visually estimated the distance from the nest to the vegetation and to the high tide line. The estimates were then assembled in three classes (frontier, near and far) (table 1.3). In João Vieira, only the coordinates and the type of emergence were recorded.

Table 1.2: Habitat around the green turtle nests. We adapted the categories described by Ferreira (2012).

Habitat	Characteristics
Cliffs	Vertical walls, more than 0.50 m high, never submerged by water
Grass	Flat sandy soil covered by short (less than 0.50 m high) vegetation
Bushes	Flat sandy soil with vegetation more than 0.50 m high but lower than 1.50 m
Forest	Flat sandy soil with trees (more than 1.50 m high)
Beach	Flat sandy beach with no vegetation cover, usually flooded in the high tide
Dunes	Sandy slopes with no vegetation or with a scarce herbaceous cover

Table 1.3: Classification of the distance estimates from the green turtle nests to the island vegetation and to the high tide line. We considered the high tide line the height observed during the Spring tides.

Class	Distance interval (meters)
Frontier	0
Near	[1-10]
Far	>10

Nest predation:

Nests were marked at random during the beach surveys and followed to ascertain their fate. All the nests were followed for ten days, to cover the period when predation is expected to occur (Gonçalves et al., 2007; Leighton et al., 2010). When a nest was marked, the habitat surrounding it (table 1.2) and the distance to the forest and the high tide water mark (table 1.3) were recorded. In the following days, predators were identified by the tracks found around the nest, a technique that was found effective in the island of João Vieira, which has the same nest predators that are found in Cavalos (Ferreira, 2012). When the nest was destroyed, we recorded the cause of destruction (predation, flooding by the sea or other reasons) and stopped following it. After September 18th, the date of the highest high tide that occurred during our study (Instituito Hidrográfico, 2016), we have made an extra survey, where we counted the amount of the remaining nests that were destroyed by the sea.

The coordinates of the nest location were captured using a Garmin® eTrex 10x portable GPS device in the WGS 84 Projection. For the binomial regression used later (see the statistical analyses section), habitat was recorded in a gradient of complexity, with 0 representing the beach habitat, 1 the dunes, 2

the grasses, 3 the bushes and 4 the forest. We also recorded the location E/W of the nests, with 0 representing East and 1 representing West (table 1.4).

Table 1.4: Variables recorded in the followed nests for the binomial regression. Variables were added in the model using Forward Selection. The distance variables were converted in to numeric variables representing an increase in the distance from the nest [1;3].

Variable	Description
Distveg	Distance to the island vegetation, estimated in distance classes (see table 1.3)
Distsea	Distance to the maximum high tide line, estimated in distance classes (see table 1.3)
Location(E/W)	Binomial variable, separates the nest by their location
Habitat	Habitat around the nest, registered in a complexity gradient [0;4].

Data analysis:

Beach surveys

To estimate the total number of nests laid during the season we applied the methodology used for the same purpose in João Veira in 2011 (Ferreira, 2012). This methodology assumes that the temporal nests distribution throughout the season is the same as what was measured in the extensive census conducted in the island of Poilão in the year 2000 (Catry et al., 2002). There is evidence that indeed the temporal variation in the distribution of the nests between different nesting seasons is small in this archipelago (Patrício et al., 2017). In that study, the authors showed that the nesting season lasts from 19 July to 14 December, with the vast majority of nesting occurring from August until October (Catry et al., 2002). We extrapolated the number of nests for the portion of the nesting period not covered by this study using those estimates. In single days in which no nest counts were possible, the value used was a linear interpolation using the nests laid the day before and the day after the missing count. This methodology was applied to João Vieira and Cavalos, where daily census were possible for a long period (34% of the breeding season was covered in Cavalos and 24% in João Vieira). For Poilão we used data gathered during the IBAP 2016 census (unpublished data) in which 28673 nests were estimated between August 3 and November 19, comprising 93% of the island's nesting season. For the island of Meio, no estimate was possible because there were only three one-day trips to the island in non-consecutive days.

To test if nesting success was dependent on the nesting habitat, a Chi-square independence test was applied, comparing the number of nests with the number of emergences registered for each habitat. In the beach habitat nesting success was almost null, probably because during the Spring tide much of the beach habitat is submersed, and so not available to the turtles to nest. Due to that, a second Chi-Square test was made excluding the emergences when the turtle remained at the beach and did not excavate a nest in a viable habitat.

Another Chi-square test was performed to compare the number of false crawls recorded in each habitat with the total amount of emergences in each habitat. Again, the number of false crawls recorded

in the beach habitats was far superior to the number of false crawls recorded in other habitats, and so two tests were made, one considering the beach habitat and the second excluding it.

Map production:

To map the distribution of the turtle nests and false crawls along Cavalos island, we first used the coordinates, captured in WGS84 and then converted to UTM 29N projection, the optimised projection for Guinea-Bissau (Snyder, 1987), of successful nesting events and false crawls. Then the island coast was divided in 50 meters segments and the total number of nests and false crawls encountered in each segment throughout the survey was depicted. To map the distribution of the nesting habitats throughout the island, for each 50 meters segment we assigned the habitat that was found around the majority of nests found within that segment.

All maps and projection conversions were drawn using Quantum Gis 2.8.9. All satellite imagery was taken by Google® and integrated in the map using Qgis Openlayers plug-in.

Nest predation:

To determine which environmental characteristics might be influencing predation (table 1.4), a binomial logistic regression was made, after testing for correlations between all variables. The dependent variable tested was predation on the nests, with 1 representing predation and 0 representing an intact nest. Variables were added in the model using forward selection. These analyses were made using IBM SPSS Statistics 24.

The logistic regression has the assumption that there is no spatial autocorrelation between the data (Peng et al., 2002). As nest predation events tend to be subject to spatial autocorrelation (Ficetola, 2007), a second test was made to verify if predation of a given nest would increase the likelihood of nearby nests being predated. We tested spatial autocorrelation using nile monitors' predation events, considering a predation event as the dependent variable (1 representing a predated nest and 0 representing an intact nest). We considered the Euclidian distance between each pair of nests for the test statistic and the test was applied to all the followed nests. Spatial autocorrelation was tested with a Moran's I test, a test that assumes that the distances between each point and its neighbours are arranged in a Gaussian distribution in a large sample size (Moran, 1948, 1950). In this test, the null hypothesis is that there is no spatial autocorrelation between the tested points (Moran, 1948).

This analysis was made using ESRI ARQGIS® Desktop 15.0 software spatial auto-correlation tool.

Results:

Nesting activity on the islands:

During the survey in Cavalos, we recorded 2230 emergences. From those emergences we identified 852 nests, which means that in Cavalos, nesting success was only 38%. Based on the number of successful nests and extrapolating to the whole nesting season, we estimated a total of 2507 nests for this island.

On the island of João Vieira we recorded 105 emergences, resulting in 45 nests were identified, which means that nesting success was 43% in this island. Based on the number of successful nests and once again extrapolating for the whole nesting season, a total of 173 nests were estimated for that year in João Vieira. For Poilão, data gathered in 2016 points to a total of 30877 nests for that nesting season (IBAP, 2017).

In Meio a total of 65 nests were found in the three census made there, with an average of 22 nests a day, almost the same as the average of 25 nests a day found in Cavalos during the month of August. The only time a survey was made in the same day in both Meio and Cavalos (August 25th) we registered 33 nests in Cavalos and 20 nests in Meio, but on that day the real number of nests in Meio is probably underrepresented as the high tide interrupted the census near its end, so, some nests might have been covered by the sea and were not counted. It was not advisable to estimate the total number of nests for the season in the island of Meio due to the small sample size.

The distribution of nests through the season was not uniform. At Cavalos we observed a minimum of 6 nests in the beginning of August, during a period of heavy rains, and a maximum of 43 nests in the beginning of August and September (figure 1.2). It is possible that there is a slight underestimation of the number of tracks registered during periods of heavy rains, which make the turtle tracks harder to detect.

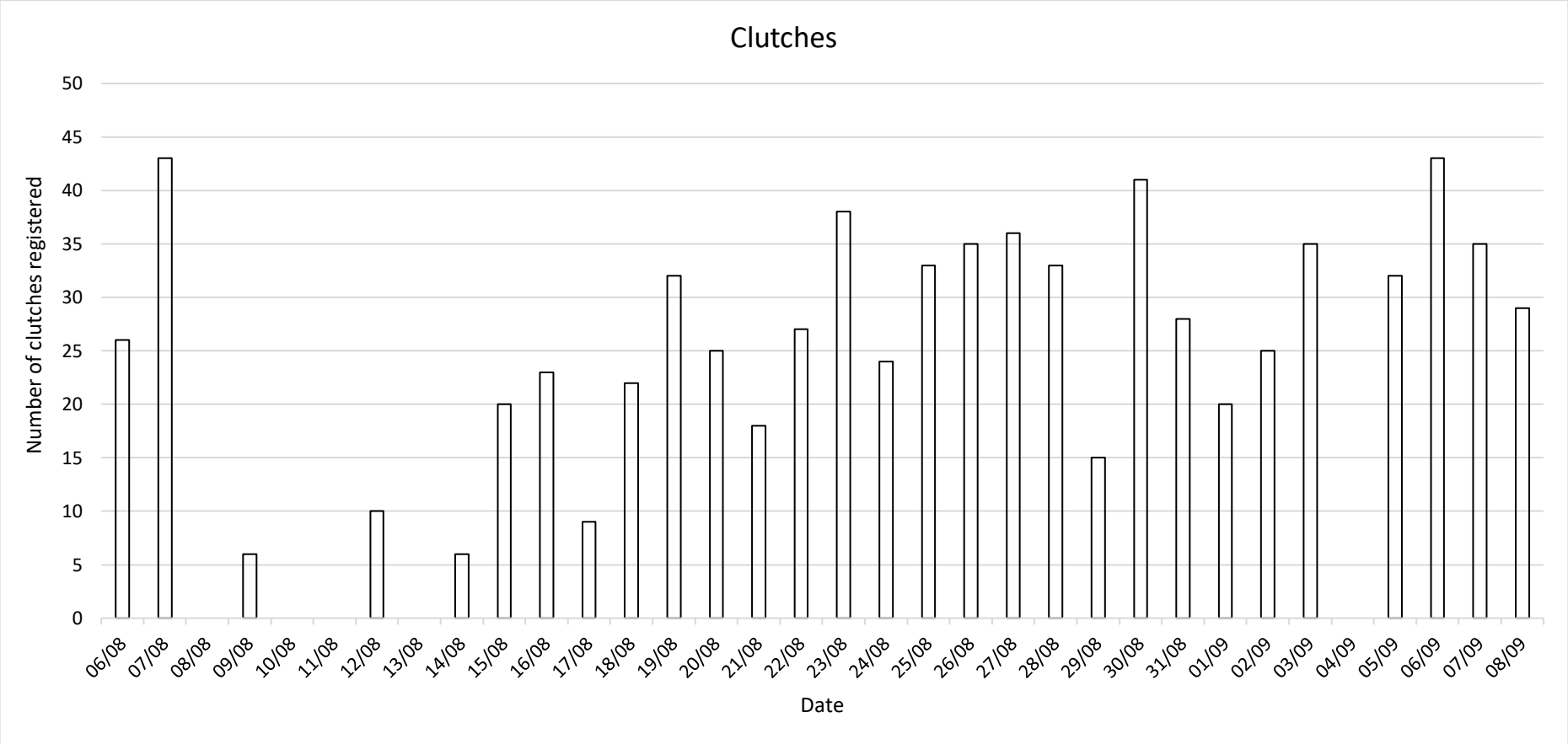

Figure 1.2: Number of green turtle nests registered by our survey each day on Cavalos. Days without observations have various reasons, such as heavy rains or other logistic problems that made impossible to conduct the beach survey.

Nesting habitats were distributed heterogeneously throughout the island. In the north and the west turtles nested mostly in the bushes habitat, while in the south and the east, the dune habitat dominates. There is a river mouth in the middle of the east coast, so naturally no nests were found there (figure 1.3).

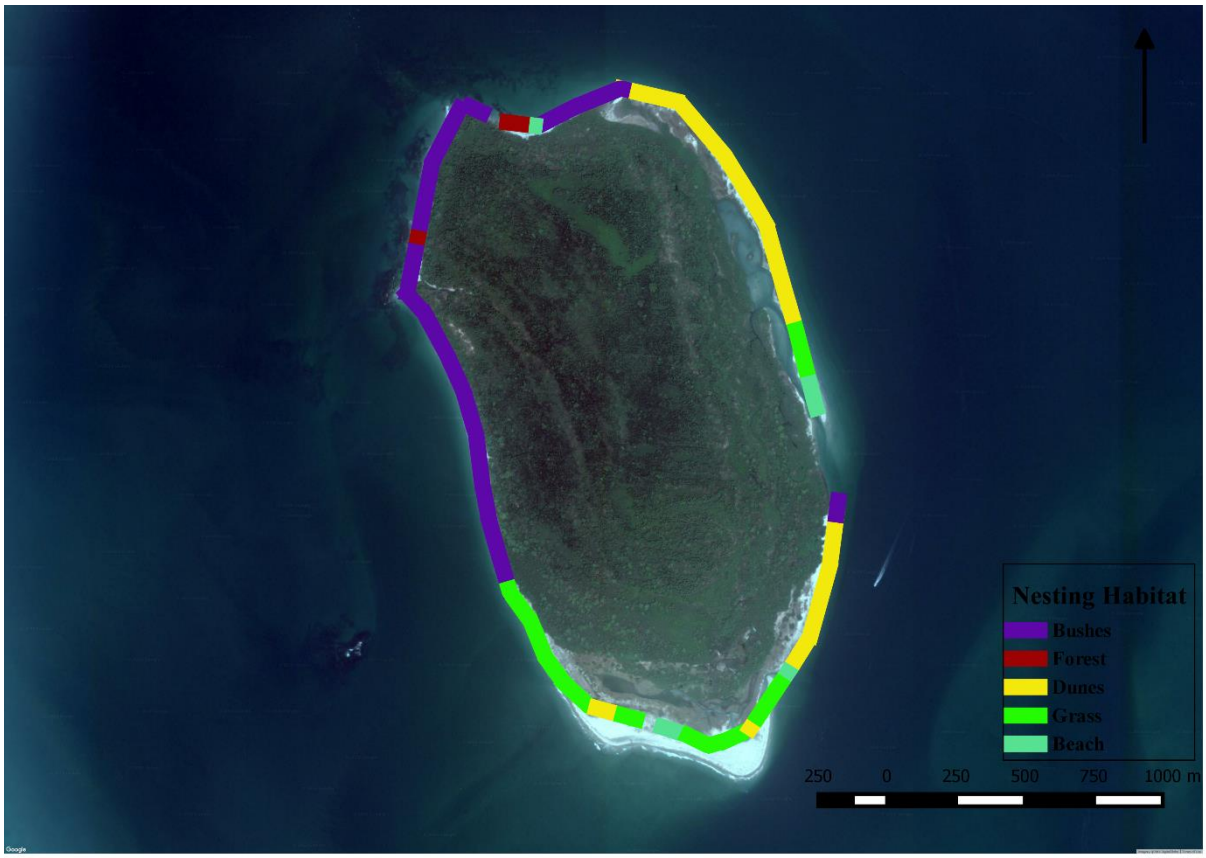

Figure 1.3: Nesting habitats in the island of Cavalos for the green turtle. The island's shore was divided in 50 meters segments and the habitat where nests were in each segment was recorded. No nests were found in the unfilled sections; the largest gap corresponds to the mouth of the small river in the eastern shore.

Nesting intensity was not uniform around the island, with the greatest concentration of nests being found in the SE (figure 1.4). The area with the highest nesting density corresponds to some of the longest dunes of Cavalos (figure 1.4). In those dunes, turtles would nest even in the slope of the dune (figure 1.5)

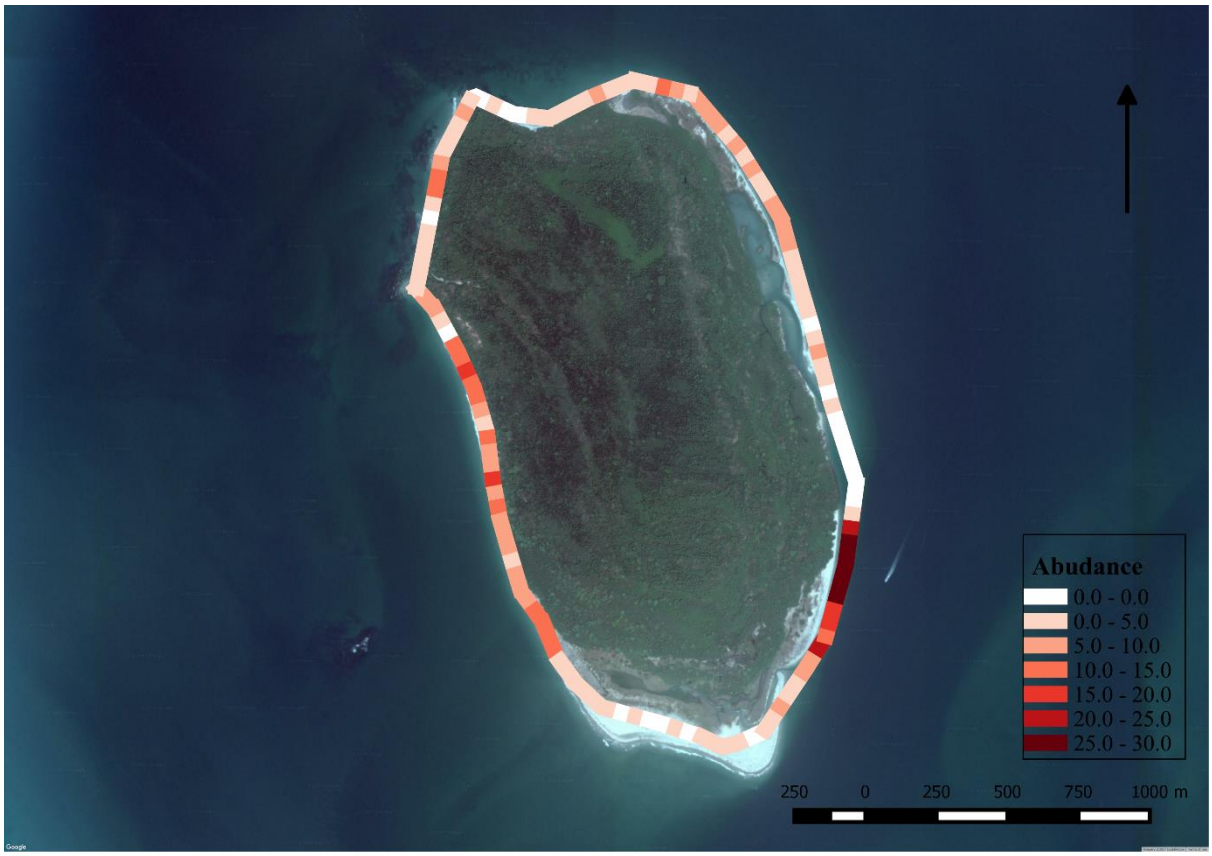

Figure 1.4: Distribution of nests throughout the coast of Cavalos. The abundance scale shows the number of green turtle nests registered during the survey period in each 50 meters segment of the coast.

Figure 1.5: Nests on the dune habitat. Note the overlapping of tracks and nests; this dune is in the area where most nests were found. The turtles would sometimes climb all the way to the top of the dune, but often they would stop in the middle of the slope and build their nests there

The distribution of false crawls throughout the island was different from the nests; false crawls appeared to be distributed more homogeneously (figure 1.6)

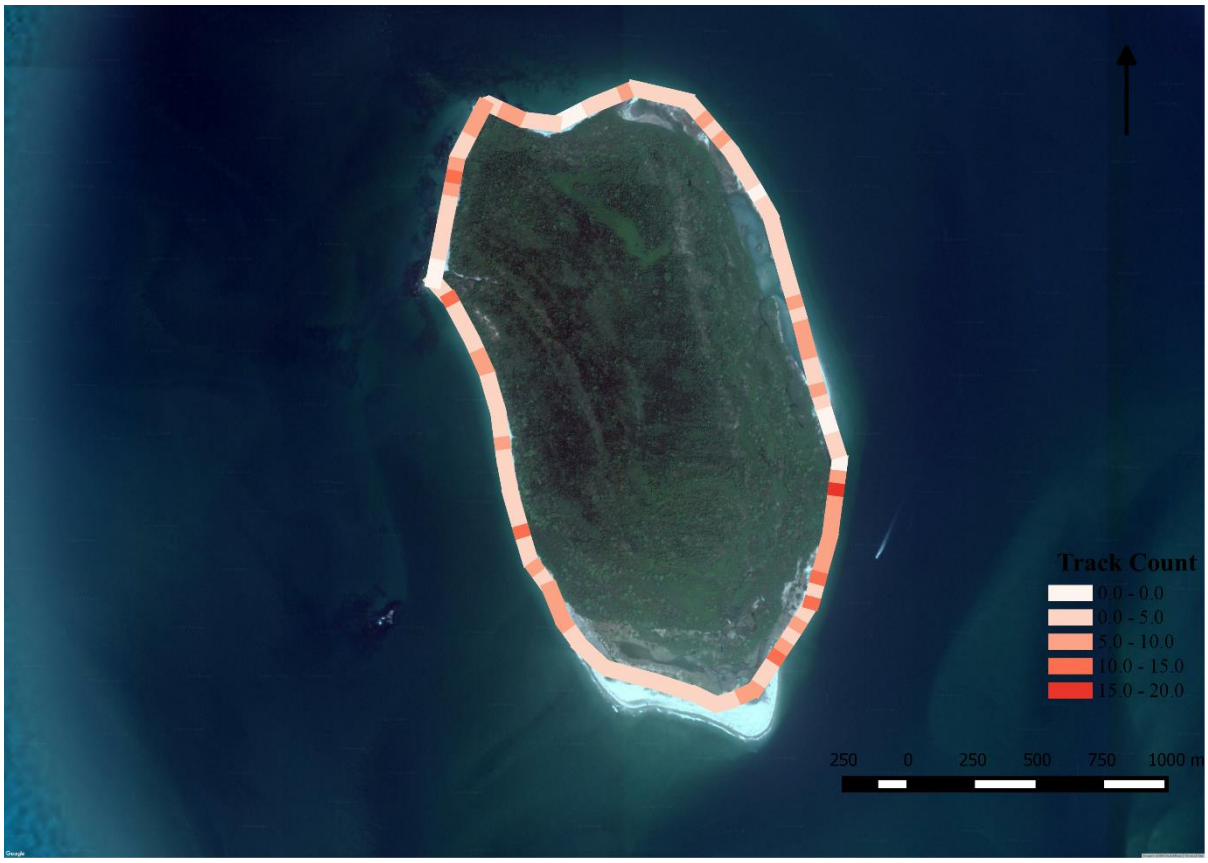

Figure 1.6: - Distribution of green turtle false crawls throughout the island of Cavalos. The scale shows the number of false crawls registered during the survey period in each 50 meters segment of the coast. The abundance scale has the same intervals and colours than the nest distribution map.

The habitat was registered for a total of 1968 emergence events. Nesting success differed among the habitats (table 1.5). All the Chi-square tests rejected the null hypothesis, indicating that both nesting success and the proportion of false crawls were significantly different among the island habitats, even after removing the beach habitat from the analysis. (table 1.6).

Table 1.5: Nesting success of the green turtle in the island of Cavalos for the different habitats. Nesting success (%) represents the percentage of emergences resulting in a turtle nest.

	Beach	Dunes	Grass	Bushes	Vegetation
Successful nests	39	363	177	180	25
Nesting attempts	45	207	159	180	35
False crawls	254	105	96	88	15
Nesting success (%)	12	54	41	40	33
Nesting attempts (%)	13	30	37	40	48
False crawls (%)	75	16	22	20	20

Table 1.6: Results for the Chi-Square test for independence on the frequency of nesting success and false tracks in different habitats. Significant values are represented in bold. In all tests the H0 was rejected meaning that nesting success and the proportion of false crawls is dependent on the habitat in which the nests and false crawls are.

Test	Test score	Degrees of freedom	p-value
Nesting success	169.0	4	**<0.01**
Nesting success excluding the beach habitat	32.0	3	**<0.01**
Proportion of false crawls	446.1	4	**<0.01**
Proportion of false crawls excluding the beach habitat	8.3	3	**0.041**

Predation rates:

A total of 64 nests were followed for the nest predation study. Of these nests, a total of 23 were predated (a predation rate of 36%). In 19 nests (30% of the followed nest) the predators were nile monitors and in 4 nests (6% of the followed nests) the predators were ghost crabs. Nile monitors predated the nests shortly after they were built, within an average of two days (average = 1.95, stdev = 0.97) since the nest was excavated. We did not find any signs of nest predation by nile monitors after more than 3 days. As for the ghost crabs, we found that on average nests were predated 5 days after they were laid, (average = 5, stdev = 3.37, N=4), although we have found a nest that was predated 10 days after it was laid. Additionally, we found that the sea also caused a high mortality in turtle nests. The nest count after the regular census and the exceptional count after the highest tide of the season, showed that the sea washed away 42% of the monitored nests (table 1.7).

The Moran'I test did not reject the null hypothesis (I=0.159; Z-score=1.121; p=0.262). This means that there was no statistically significant spatial autocorrelation between the predated nests.

Table 1.7: Causes for the loss of green turtle nests in the island of Cavalos. The "other" category represents a single nest whose marker was probably knocked down by a turtle and lost.

Cause	Nest loss	Percentage (%)
Lizard predation	19	30
Crab Predation	4	6
Flooding	27	42
Other	1	2
Intact nests	13	20

There were nine confirmed sightings of pigs or of their activities on the beach, but there was no evidence of nest predation during the survey period. We analysed the stomach content of two pigs that were hunted by an inhabitant of João Vieira and no remains of eggs or sea turtle hatchlings were found; only possible roots and fruits like "mandipede" and palm nuts. Animal remains were absent.

Logistic Regression:

After checking for correlations, we have seen that the location of the nests were strongly correlated to the habitat variable (Spearman's rank correlation rho= -0.581, p <0.01) and to the distance to the vegetation variable (Spearman's rank correlation rho=.409, p< 0.01) (Annex 1), and so, we discarded the discarded the nest location variable from the model as the distance to the vegetation and the nests habitat are more ecologically significant than the E/W location of the nests. For the regression, only one variable was considered significant: the distance to the island vegetation, with a negative coefficient meaning that the further away from the vegetation, the lower the predation probability (table 1.8).

Table 1.8: – Results of the logistic regression for the variables influencing predation on green turtle nests in Cavalos. From the variables tested (distance to the vegetation, distance to the sea and habitat), only the distance to the vegetation was seen as having a significant effect on predation. Significant values (p-value < 0.05) are represented in bold.

	B	S.E.	Wald	df	Sig.	Exp(B)
Distveg	**-0.763**	0.382	3.997	1	**0.046**	0.466
Constant	0.907	0.907	1.001	1	0.317	2.478

Discussion:

Nesting intensity throughout the islands:

We estimated a total of 2507 nests for the island of Cavalos. Using the data gathered from IBAP during the same nesting season, we estimated 30877 nests for Poilão. Finally, in João Vieira we estimated only 173 nests for the 2016 nesting season. This means that Poilão, although being the smallest of the three islands (IUCN, 2002), maintains the highest nest density and intensity, followed by Cavalos and lastly by João Vieira. Meio seems to have some importance with the same average nests per day as Cavalos However, given our small sampling effort, it is not currently possible to ascertain how intensively do sea turtles use this island. There are significant differences in the human occupation of the different islands. In João Vieira there is small but permanent touristic resort as well as temporary fishing camps so there is human presence in the island year-round. In Meio, although there are no permanent inhabitants, there are some occasional fishing camps, which have been showing some tendency in the last few years to become permanent (Catry et al., 2010). Additionally, these islands are periodically subject to the "m'pam-pam" slash and burn agriculture (IUCN, 2002), which happens during the rainy season, coinciding with the peak of the sea turtle nesting season (Catry et al., 2002). As was stated before, Poilão is the most remote and sacralised island (IBAP, 2008), as well as the island that is being monitored for the longest time (Catry et al., 2010), so it probably provides the safest place for adult sea turtles to nest. This seems to point that turtles are very sensitive to human disturbance and use preferentially the islands where historically it is less frequent, even if that means risking losing their nests due to the nesting activity of other turtles.

Nesting activity seems to vary substantially between nesting seasons. In Poilão, an estimated 7397 nests were registered in 2000 (Catry et al., 2002), in 2007 that number rose to 29 016 (Catry et al., 2009) and, in 2011, a census made by IBAP that covered 91% of the nesting season resulted in an estimated 31 804 nests (IBAP, unpublished data), slightly more than the 30877 total nests estimated for 2016. In João Veira, in 2011, a total of 596 nests were estimated (Ferreira, 2012), but in 2016, that number decreased to 173 nests.

It is not unusual to observe large differences in number of nests among breeding seasons in the same location (Broderick et al., 2001). That phenomenon happens in most of the major sea turtle nesting grounds. As an example, the number of nests of loggerhead sea turtles registered during a regular monitoring program on the island of Boavista, Cabo Verde, rose from 1652 in 2015 to 3668 in 2016 (Turtle Foundation, 2017). Apparently 2011 was a peak year for the turtles of the PNMJVP. In 2016 there was a slight reduction in the numbers at Poilão and an accentuated reduction in the nesting activity in João Vieira. Crashes and peaks in nesting activity may be related to unusual weather events, such as heavier rains (Chaloupka, 2001). Sea turtles do not breed every year. As they undergo trough migrations of thousands of kilometres (Limpus et al., 1992; Seminoff et al., 2008) between their feeding and nesting grounds, they usually take a few years to replenish their energies. (Lutz et al., 2003). It is still relatively unknown where do the turtles of the Park go to feed, and the limited data suggest that there are several feeding grounds for the turtles of the PNMJVP, with turtles migrating to the Park National du Banc D'Arguin in the Coast of Mauritania and to the coast of Senegal (Godley et al., 2003). This interesting data seems to suggest that there are several feeding grounds for the population nesting in Poilão, but

once again as the sample size is very small, there is a lot of information about these turtles that is still unknown.

There is some (rare) documentation of sea turtles using different islands to nest during the same season (Godley et al., 2003), so, it is possible that at least part of the population of Cavalos and João Vieira indeed uses the same feeding areas as those from Poilão. However, intensive tagging and satellite tracking campaigns are still needed to ascertain the frequency of these events and whether the turtles from the archipelago belong all to the same population. If the turtles of the different islands indeed belong to the same population, it is possible that the reason for the much larger drop in the number of turtles nesting in João Vieira than in Poilão in 2016 is the safety of Poilão (Catry et al., 2010). As in João Vieira turtles are occasionally hunted (we have found some turtle shells during our surveys), they might be avoiding the island. Additionally, as the number of turtles nesting in João Vieira is much smaller than in Poilão, stochastic events will have a higher impact in that island, as large numbers tend to soften the impact of stochastic variations (Barabási and Albert, 1999).

With only 38% of the emergences resulting in nests, half of the 76% registered in Poilão (Catry et al., 2002) and of the 71,1% registered in João Vieira in 2011 (Ferreira 2012), nesting in Cavalos seems to be riskier than in the other studied islands of the archipelago. At Cavalos, nesting success was significantly different between the different habitats, with the dunes being preferred over the other habitats (54% of tracks in dunes resulted in a nest) and the beach habitat being the less preferred (only 12% of the tracks resulted in a nest).

Avoidance of the beach habitat was not unexpected. In Cavalos, during the Spring tides, almost all of the beach was submerged by the sea; any nest that had been built there would be flooded, and the embryos killed. The selection of dunes as a preferential nesting habitat by the green turtle has been registered before (Bouchard and Bjorndal, 2000) - this is a habitat safe from tides, as well as from vegetation roots that can hinder nest building by female turtles and wrap around the eggs, leading to deformities in the hatchlings or even the death of the embryos (Wyneken et al., 1988). Nesting near the island forest also has the disadvantage of an increased predation risk by nile monitors as our results showed. However, it has been shown that individual sea turtles may have different habitat preferences (Bjorndal and Bolten, 1992; Kamel and Mrosovsky, 2005), particularly in areas susceptible to erosion (Bjorndal and Bolten, 1992) This renders the populations adaptable to changes in the ecosystem and may provide them with a tool to resist the impacts of climate change.

False crawls were distributed evenly around the island (except for the southern shore which seems to be avoided by the turtles) (fig 1.6); however, considering the proportion of false crawls found in each habitat, we can see that turtles give up mostly when they are still on the beach. This seems to point that the reason for the nests to be focused in the southeast dunes is not because of the characteristics of the approach to shore, but rather because of the characteristics of the habitat itself, otherwise, we would also see a higher number of false crawls there.

The lower nesting success in Cavalos when comparing with the nearby islands of the PNMJVP can be explained by the lack of suitable habitat in most of the island. As we have seen, it appears that turtles come ashore randomly along the shores of the island; however, most of the island shore is composed of suboptimal nesting habitat, where the sea reaches the island vegetation during the high tide. As such, overall nesting success is low. However, if we look to nesting success in the preferred dune habitat, we see that that value (54%) is closer to the values registered in Poilão and João Vieira.

We have seen a lower number of turtles nesting in herbaceous habitats than expected, when compared with the nearby island of João Vieira, where that habitat was the preferred one (Ferreira, 2012). This may be explained by the uneven distribution of the habitats throughout the island. The herbaceous habitat is mostly located in the southern part of the island (fig 1.3), where the offshore is characterized by sand banks and shallow waters (Cuq, 2001). In Ascension, long shallow offshore approaches and beaches with gentle slopes were rejected by green turtles as sub-optimal nesting habitats (Hays et al., 1995). The authors suggested that turtles need a relatively abrupt change in the beach slope as a cue to start digging their nests (Hays et al., 1995), this cue was mostly unavailable in the herbaceous plains areas as they were almost levelled with the beach (and the edge of these plains was flooded by the sea during the spring tide). In João Vieira, these plains were separated from the beach by a small slope, which probably provided the turtles with the cue they require to start digging a nest. A recent study on the turtles nesting in the Bijagós showed that they choose to nest in elevated areas, above the spring tide maximum height, thereby protecting the nests from flooding (Patrício et al., 2018). Indeed, as we have seen with our study, where more than 40% of nests were destroyed by the sea, there is probably a very strong selective pressure toward nesting in high ground and this must be one of the decisive factors concerning nest site selection. In the future, there may be some shift towards nesting in shaded areas (Patrício et al., 2017; 2018) because with the climate changes, nests dug in open sand will probably only produce females due to the fact that in sea turtles, the sex of the hatchlings is determined by the temperature of the eggs during incubation (Mrosovsky and Yntema, 1980).

Feral pigs:

No signs of predation by feral pigs were found through the entire survey period, although there were nine sightings of pigs or pig tracks during that time and once a family with 2 suckling piglets was observed. This is different from what can be found in most sea turtle nesting grounds where feral pigs are nest predators (Cruz et al., 2005; Seward et al., 2004; Zárate et al., 2013). as there are even places where pigs are the main nest predator (Hitipeuw et al., 2007).

As the inhabitants of nearby islands often travel to Cavalos to hunt the pigs it is possible that there is only a small pig population on the island and so they do not need to go to the beach and risk exposure while digging nests for eggs. Alternatively, pigs are very intelligent and quick learners, and as such able to adapt their behaviour to better cope with stress (Kornum and Knudsen, 2011). Because of that, it is possible that they have learnt to avoid the island shore when there are people on the island, so, during our study, we may have accidentally scared the pigs and caused them to remain secluded in the forest, going to the beach less frequently than they might have done otherwise.

Even if these pigs present no danger to sea turtles, giving their generalist behaviour they are known to cause havoc in small insular ecosystems (Nogueira-Filho, 2009; Roemer et al., 2001) changing the ecosystem and facilitating the invasion of foreign plants and animals (Nogueira-Filho, 2009).

Nest predation:

In the three islands of João Vieira and Poilão National Park studied so far, the nesting intensity and predation rates seem to differ. Although being the largest of the three islands, João Vieira is also the one where nesting activity seems to be smaller and predation rates higher Ferreira (2012) refers predation rates of 76% and estimated a total of 596 nests for the entire season in this island). At Cavalos, as our results showed, there are intermediate nesting intensities and predation. Predation rates are around 36% and we estimated a total of 2507 nests during the nesting season. Finally, Poilão is the island with the most intense nesting activity and the lowest predation rate (only 4% of marked nests were predated in 2000) (Catry et al., 2002).

The huge difference in predation rates between these islands is probably due to predator satiation, as the predators in Poilão have an abundance of eggs available to consume (Eckrich and Owens, 1995). This happens because, while in Poilão thousands of nests are dug each season (Catry et al., 2002, 2009), in João Vieira in 2011, only 596 nests were estimated for the entire nesting period (Ferreira 2012). Additionally, in Poilão almost a third of the nests have eggs around them, because the turtle that was digging them dug out older turtle nests, and so predators do not need to dig up a nest to gain access to the eggs (Catry et al., 2009).

The ghost crab, which is a typical egg predator in most sea turtle hatcheries (Strachan et al., 1999; Tureli et al., 2009) and is a documented nest predator in Poilão (Rebelo et al., 2011), was responsible for very little predation in Cavalos during this study and did not predate any nest in João Vieira in 2011 (Ferreira, 2012). This is unlike the situation in most sea turtle hatcheries in which these crabs are usually one of the most important nest predators (Magnuson et al 1990).

Ghost crabs are burrow dwellers (Strachan et al., 1999; Tureli et al., 2009), and usually dig their burrows a few meters above the high-water line (Ferreira, 2012; Strachan et al., 1999), the same area that sea turtles use to build their nests. As such, they are able to reach egg chambers even when they are not actively searching for them, which might explain why they are able to predate turtle nests during all their existence.

This means that our study, although having covered most of lizard predation events, probably did not detect all predation events by ghost crabs. Predatorial activity by ghost crabs can be detected by spotting egg shells around a turtle's nest (Barton and Roth, 2008), but as the nile monitors also scattered eggs around the nests, and their tunnels are much larger than the crabs' burrows, it is possible that we failed to notice some of the crabs activity and as such their predation rates may be higher than reported. However, a study in which nests were monitored with cameras showed that the accuracy of this method is quite high (Ferreira, 2012), so if this has happened it was probably not significant. The nests were not followed through all their existence, so some later predation might have occurred that we could not register, however, most predation events occurs in the first week of the nests existence (Gonçalves et al., 2007; Leighton et al., 2010), so predation occurred after we stopped following the nests, it was probably not significant.

Ghost crabs seem to play a very modest role as turtle nest predators in these islands. With predation rates below 5% in the three studied islands (Catry et al., 2009; Ferreira, 2012) they appear to represent the role of an occasional or opportunistic predator instead of relying on turtle eggs as a food source. It is possible that the unrestricted presence of the nile monitors ends up preventing the grabs from effectively predating the turtle nests. It has been documented that varanid lizards predate on ghost crabs (Blamires, 2004), so they might be causing the crabs to be more cautious. Indeed, it has been showed in Florida that predation by ghost crab increases significantly when a higher tier predator like the raccoon, *Procyon lotor* (Linnaeus 1758) is removed (Barton and Roth, 2008). Even in the Bijagós, we can see that in other islands of the

archipelago were the lizards are killed by the local populations, predation rates by ghost crabs are much higher (Catry et al., 2009).

It is also interesting to note that predation by nile monitors occurred soon after a nest was dug (on average two days after and never after more than 3 days had passed) while the crabs predated the nests later (although we had only 4 nests predated by the crabs, they were predated on average 5 days after they were dug, with one nest being predated after ten days). It is not a new information that nile monitors predate nests shortly after they are dug. For instance, in the nearby island of João Vieira, where the only registered nest predator was the nile monitors, more than 85% of the predated nests were predated in the first two days (Ferreira, 2012). For another example, in Ulithi Atoll, an island in Micronesia, all of the 25 predation events registered occurred in the first five days since the nest was dug (Cruce, 2009). As for the crabs, a study in Tortuguero, Costa Rica showed that only 64% of the nests predated by the crabs were predated before four days had passed since oviposition (Fowler, 1979). This shows that although the bulk of crab predatorial activity occurs early in the nest life, it is not so restricted to the first days. As predation by lizards was high in both islands and concentrated in the first few days of the nest, it is possible that most easy to detect nests were quickly predated by lizards and not available to crabs, which usually predate when the nests are a bit older (Fowler, 1979). However, ghost crabs should not be dismissed as unimportant for the nesting ecology of sea turtles as they are important hatchling predators (Peterson et al., 2012; Rebelo et al., 2012) and we have not made any measurements on hatchling predation, so, their impact on that phase of the turtles' life cycle is unknown at Cavalos.

Turtle nests were slightly more prone to predation by lizards when built near the vegetation than far from it. This result was expected; on Barbados there seems to be a higher predation risk when the nests are dug inside the forest and a lower predation risk when eggs are laid in more open spaces like a beach or sand dunes (Leighton et al., 2010). Like on João Vieira (Ferreira, 2012), the only factor that was seen as important to predation at Cavalos was the distance from the nest to the forest vegetation. As the nile monitors take refuge inside the forest (Shine, 1986), it is normal that nests that are built closer to this habitat are more prone to being predated than nests that are built far from it (Marchand and Litvaitis, 2004). In areas where human presence is a constant, we would have probably less predation in exposed habitat like the dunes, like what was seen in Barbados (Leighton et al., 2010).

With this work, we showed that Cavalos has an intermediate importance for the nesting turtles of the PNMJVP. Poilão given its small size is very vulnerable to the rise of the sea level, which could flood the areas sea turtles currently use to nest. This might cause the other islands of the PNMJVP to become more important for nesting females. Given the large extent of the dune habitat on Cavalos where the turtles can build their nests higher up and relatively safe from the sea (there is evidence to support that they favour building their nests in higher ground (Patrício et al., 2018)), it is possible this island will see an increase in the number of females using it to build their nests. As such, it is important that it retains its protected status.

CHAPTER 2: How do nile monitors attack sea turtle nests and what can we do about it? A study on nest protection techniques.

Abstract:

Sea turtles are in decline worldwide. They face human predation during all of their life cycle, and in developing societies their meat and eggs can be an important source of protein. In Cavalos island (part of João Viera and Poilão Marine National Park, Bijagós archipelago, Guinea-Bissau) however, there is little human activity so one of the most important threats to nest survival is natural predation, in particular by nile monitors, *Varanus niloticus* (Linnaeus, 1758), which are the main turtle eggs predator of the Bijagós archipelago.

In this study, we analysed the mechanisms that nile monitors use to detect recently dug green turtle nests, *Chelonia mydas* (Linnaeus, 1758). We also tested three different nest protection techniques (disguising scent cues; disguising visual cues and placing a metal net over the nest) to reduce predation. We observed that the lizards could detect nests using only scent cues. Given that result and considering that all the treatments resulted in reduced predation rates, we suggest that camouflaging a nest's scent may be a management option to reduce predation rates in sensible areas without damaging the local ecosystem.

Key words: *Varanus niloticus*: nest protection: predation cues: green turtle: turtle eggs

Introduction:

To help protect sea turtle populations, several conservation programs focus on protecting their nests and hatchlings (Marcovaldi and Chaloupka, 2007; Turtle Foundation, 2017) as that is when sea turtles are easier to access by terrestrial predators (including humans) and in their most vulnerable phase (Marcovaldi and Chaloupka, 2007). A relatively common way to do that is the removal of predators near the nesting area (Engeman et al., 2002, 2003). However, this can be very expensive (Engeman et al., 2002) and disturb the local ecosystem (Barton and Roth, 2008). Additionally, when there are two or more predators from different trophic levels, the removal of the top predator can lead to an increase of the lower one, which might worsen the problem instead of solving it (Engeman et al., 2002).

To try and solve the downsides of the previous method, some alternative nest protection techniques have been used; for instance, covering the nest with metal nets has been successfully applied in Tunisia to protect them from canids (Yerli et al., 1997) and the use of aluminium mesh cages around recently dug nests has seen some success in reducing nile monitor predation (Lei and Booth, 2017). Based on the ecology of the predators, additional protection techniques might be used, such as disguising the cues predators use to identify the nests. Predators can use a wide variety of cues which can be olfactory, visual, tactile or a combination of them (Oddie et al., 2015; Blamires et al., 2003). In turtle nests, a visual cue might be the sand dispersed around the nest, which would be a tactical cue as well, as the sand in a nest is less compacted than the sand around it (Blamires et al., 2003). Another cue that some predators can use is the water content in the sand,

as early in the morning the dugout sand in a nest is wetter than the surrounding sand (Oddie et al., 2015). As for scent cues, the strongest one would be the scent of the female fluids left in the nest while laying (Oddie et al., 2015). To know which protection technique would be the most efficient, a comprehensive study of the predators existing in the nesting areas and what cues they may be using to detect the nests is required. For instance, the smoothing of the sand above a nest could work to hamper a visual based predator, but it would probably require chemical concealing as well to protect the nests from predators which use chemoreception to detect the nest (Blamires et al., 2003).

Varanid lizards are large reptiles, starting their activity mid-morning and remaining active during the day (Shine, 1986). They are generalist predators and are generally able to adapt their feeding habits to the food sources available in their environment (Losos and Greene, 1988). At João Vieira and Poilão Marine National Park (PNMJVP), the nile monitor, *Varanus niloticus* (Linnaeus, 1758) is the main predator of sea turtles nests, predating up to 76% of the nests in the island of João Vieira (Ferreira, 2012), but only around 3% of the nests in the island of Poilão, where the highly abundant nests lead to rapid predator satiation (Catry et al., 2002).

In areas where there is low nesting density and the local nile monitors can predate upon a large proportion of nests, it is therefore important to test easy and non-expensive ways to protect the nests, especially when that predator is active during the night or in the early morning like the nile monitor (Shine 1986) and so there is not a lot of time that can be spent on each nest.

In this study, we tested the effectiveness of three different nest protection techniques to protect sea turtle nests from predation by nile monitors. Besides that, we have made a preliminary analysis of the mechanisms used by this predator to identify newly dug nests.

Methodology:

Study site:

This research was conducted in Cavalos, an uninhabited island in Parque National Marinho João Vieira e Poilão, (PNMJVP), (João Vieira and Poilão Marine National Park), a marine protected area comprising 4 small islands and some islets and sand banks in the south-east of Bijagós archipelago, Guinea-Bissau (Catry et al., 2010). The climate is characterized by alternating dry (November to May) and wet (May to November) seasons with an annual rainfall of 1500 to 2000 mm (Catry et al., 2010). This archipelago is of continental origin as it originated from the flooding of the ancient river Geba delta, which resulted in the peculiarity of having mostly shallow waters and huge intertidal areas (95% of the sea surrounding the archipelago's islands is less than 30 meters deep (Rebelo and Catry, 2011)).

The island of Cavalos has an area of 210 ha (IUCN, 2002) and a coastline of 7 kilometres, almost all of it accessible for sea turtles to nest (see chapter 1 for more details). There is no permanent human settlement in this island; however, occasionally small fishing and touristic vessels may come ashore for a few hours. Cavalos, like the other islands of PNMJVP is the traditional property of a "tabanca" (village) of the nearby island of Canhabaque (Catry et al., 2010). During the "fanado" (a coming of age ceremony), some men from Canhabaque come to this island and stay there for two or three days (Cross, 2014) consuming adult sea turtles and eggs during that time (Catry et al., 2010).

The main turtle nest predator registered in the park is the nile monitor, Varanus niloticus, there is also some predation by Ghost crabs, *Ocypode cursor* (Linnaeus 1758) in Poilão, but only 1% of marked nests were predated by them (Catry et al 2002). In João Vieira, there is no record of predatorial activity by ghost crabs, although they are present in the island (Ferreira, 2012). Both species are present at Cavalos, but the ghost crabs were not significant nest predators there (see chapter 1). There is also a population of feral pigs in that island, however, and contrary to what it was expected (Cruz et al., 2005; Hitipeuw et al., 2007; Sewer et al., 2004), there are no evidences of them disturbing the turtle nests in any way (see chapter 1).

Field Methodology:

Protection techniques tested:

We have made some nest protection treatments to assess their efficacy in preventing or reducing susceptibility to predation. We compared the predation rates in the treated nests with the predation rates observed in 64 natural nests randomly chosen around the island. We have applied three different treatments:

i) Scent covering:

Thirty millilitres of a 5% V/V clove essence aqueous solution were sprinkled in the sand on top of the nest and in the area around it. Clove essence can be a deterrent of predation, as its

strong scent may superimpose the eggs/turtle scents (Oddie et al., 2015). This treatment was performed on 26 nests.

ii) Track covering:

The sand in the area of the nest and the tracks leading to and from it, was moved using a spade and a rake, to visually disguise the turtle activity. The sand was revolved no more than ten centimetres deep to avoid destroying or disturbing the egg chamber. This treatment was performed in 31 nests.

iii) Nest protection:

The nest was covered with a square metal net measuring one square meter and with a one square centimetre grid, centred above the egg chamber. The net was placed ten to fifteen centimetres deep and then covered with sand (figure 2.1). The net in intact nests was removed in the first week of September to allow hatchlings to emerge. The removal will not affect the efficiency of this protection as nest predation by vertebrates occurs mainly in the first few days after it is excavated (Gonçalves et al., 2007; Leighton et al., 2011). This treatment was performed in 26 nests.

Figure 2.1: A green turtle nest being protected with a metal net as part of the metal nets protection technique. The centre of the net was aligned with the egg chamber.

Besides the experiments with real nests, two more experiments were conducted, using artificial nests, to identify the cues (visual or scent) that might be used by the predators to identify them.

Man-made nests:

When a nest that would be naturally destroyed (for instance, when it was built below the high-water mark or the eggs were too shallowly buried) was found, its eggs were carefully gathered in a bucket (following recommendations for a safe egg transfer (Sönmez and Özdilek, 2011)) and reburied in a nearby spot with similar habitat characteristics but above the high tide water mark. The new false nest was dug carefully so that only a minimum of sand was disturbed. In the end, the revolved sand was covered by a thin layer of dry sand to keep the moisture level and the temperature of the sand above similar to the surrounding sand, as wet and loosely packed sand might be a cue to potential predators (Oddie et al., 2015). Doing this minimized the number of visual cues inadvertently left by our activity. This experiment was conducted to try to make the nests identifiable only by the scent cues provided by the eggs. We dug 32 nests using this methodology.

False nests:

To test if the predation on the man-made nests was due to the presence of the eggs inside it or just because the lizards were aware that the sand was dug, false nests were built trying to mimic as much as possible the ones turtles build. An egg chamber was first dug with a spade at the depth that could be found in a natural nest (more than 50 cm deep, see Sönmez and Özdilek (2011) for an example); secondly, a body pit was dug in front of the egg chamber and sand was thrown above it to mimic the camouflage activity of real turtles. Afterwards, false turtle tracks, at least ten meters long were built, leading to and from the nest (figure 2.2). In this case there were no eggs in the egg chamber so that the predators would have to resort only to visual and tactile cues to identify the “nest”. A total of 25 nests were built using this method.

Figure 2.2: A false, man-made green turtle nest built in Cavalos. The nest has no eggs in it to test if the nile monitors would still try to predate the nest with only visual cues available to them.

All the treatments were applied in the early morning, before any sign of nile monitor activity was seen. During the application of all the experimental treatments except "track covering", an effort was made to leave the turtle tracks as unmodified as possible

Nests were followed for at least ten days. which is the period when the bulk (Gonçalves et al., 2007; Leighton et al., 2009, 2011) of predatorial activity is expected to occur. Whenever a nest showed signs of predation, the predator and the date of predation was recorded. In the false nests, as no real predation can occur given that there were no eggs inside them, we considered the nest as "predated" if we found nile monitors' burrows in the "nest".

Statistical analyses:

Spatial autocorrelation:

We used a Moran's I test to verify if the nests selected for the experiments were indeed randomly selected. As nest manipulation needed to stop once predatorial activity started (nile monitors start their activity mid-morning (Shine, 1986)), some areas of the island might have been overrepresented. In this test, we considered the distance to the nearest neighbour of the selected nests using the Euclidian distance between them. The variable to be tested for spatial autocorrelation was whether the nest was selected for the experiments.

A second Moran's I test was used to verify if the predated nests including the treated ones were randomly distributed along the island coast. In this test all the treated nest and the false nests with eggs were included and the variable tested was whether the nest was predated. Once again, we measured the Euclidean distance between each nest and its neighbours.

These analyses were made using ESRI ARQGIS® Desktop 15.0 software spatial auto-correlation tool.

Predation experiments:

To test if the reduced predation rates observed in the treated nest resulted from the treatments applied or were the fruit of stochastic events, a one-way Fisher exact test was used comparing the observed and expected number of predated nests for each experiment. This test has the premise that the observed 2x2 table is one of the many possible 2x2 tables that could have been observed with the row and the column totals fixed at their presently observed values (Gibbons and Chakraborti, 2003) and calculates how unlikely that distribution is. It is suitable for expected values smaller than 5, when the Chi-Square test for independence is unreliable (Gibbons and Chakraborti, 2003). Our null hypothesis was that there were no statistically significant differences in predation between any of the treatments applied and the control nests. The alternative hypothesis is that control nests are more prone to predation than the treated ones. This test was made comparing each individual treatment with the control nests, so three tests were

made: one comparing the metal net treatment with the control nests, one comparing the scent treatment with the control nests and finally one comparing the erased treatment with the control nests.

We also used a two-way Fisher exact test to compare the expected and observed predation rates between the false nests and the man-made nests. In this test, the null hypothesis was that there were no statistically significant differences in predation between the different kinds of artificial nests and the alternative hypothesis is that predation rates are higher in one of the artificial nests.

Results:

Spatial autocorrelation:

Both Moran'I tests did not reject the null hypothesis (table 2.1), meaning that there is no statistical evidence for spatial autocorrelation in the selection of nests to be followed for the experiments or in the nests predated by the lizards.

Table 2.1: Moran'I test for spatial autocorrelation between the selection of the green turtle nests to be used in the experiments (row 1) and the green turtle nests predated by nile monitors (row 2). In all the tests, H0 (no spatial autocorrelation) was not rejected.

Test	Index	Z-score	p-value
Nest selection	-0.008	-0.519	0.603
Nest predation	-0.023	-0.773	0.439

Predation experiments:

Control nests suffered 30% predation by lizards (19 nests in 64 were predated). All the treatments tested resulted in lower, and relatively similar, predation rates than the control nests; the metal net experiment was the one with the greatest reduction (from 30% to 12%). While false nests showed no predation at all, man-made nests had a slightly smaller predation rate than the controls, but higher than the nests subject to experimental treatments. The differences found in the number of predated nests are not statistically significant, although they are very close to the 0.05 threshold, especially in the metal net and the erased treatment where the p-value was 0.057 and 0.059 respectively (table 2.2).

Table 2.2: Predation rates of green turtle nests by nile monitors in the different treatments. The p-values for the results from the one-way Fisher exact tests are displayed in the last column. All the tests were made comparing the treatments with the control (unmodified) nests.

Treatment	Sample size	Predated nests	Predation rates	p-value
Control	64	19	0.30	
Metal net	26	3	0.12	0.057
Scent Covering	28	4	0.14	0.093
Track Covering	31	4	0.13	0.059
Man-made nests	32	7	0.22	
False Nests	25	0	0.00	

There was a statistically significant difference in the number of predated nests between the two false nest treatments, with predation occurring only in the man-made nests with eggs (table 2.3)

Table 2.3: Two-way Fisher exact test results and contingency table for the predation of false and man-made nests by nile lizards. The p-value is displayed in the last column. Values in bold represent significative (p-value <0.05) results.

		Predation		p-value
Treatment		Yes	No	
Man-made Nests	Observed	25	7	**0.015**
	Expected	28.1	3.9	
False Nests	Observed	25	0	
	Expected	21.9	3.1	

Discussion:

All treatments resulted in lower predation rates than the control nests. All the treatments had a similar effect on predation, we saw a decrease from 30 % predation rates in the unmodified nests to 14 % predation rates in the scent treated nests, 13% in the erased nests and 12% in the metal net nests. These differences were not statistically significant, although the p-values were very close to the 0.05 threshold (e.g., a p-value of 0.053 for the net treatment). Given our small sample size, the lack of significance is probably due to that and not necessarily to mere stochastic events.

The use of metal nets, which has been very successful, protecting nests from land predators such as canids with almost 100% efficiency (Ratnaswamy et al., 1997; Yerli et al., 1997), is not very effective with the lizards, probably due to their ecology. While dogs and other carnivores are able to dig efficiently, they are not burrow dwellers and so, they are not adapted to dig large burrows or tunnels. On the other hand, the lizards, who use burrows for their daily activities (Blamires, 2001), have longer and more complex tunnel systems and are perfectly able to dig horizontal tunnels. This gives them the ability to bypass the net since it cannot be placed very deep in order not to disturb the nests. This problem could probably be reduced with the use of larger nets, as was done with some success in Queensland Australia (Lei and Booth, 2017) or if they were placed in a cage system with a lid that could be removed before the expected hatching period. However, in areas where density is high, a large net could hinder other turtles trying to nest there and it might be damaging to the dunes digging large areas of sand. Additionally, a larger net would also require more time spent protecting each nest, which since the lizards' peak activity is in the morning (Shine, 1986) would mean that in order to protect a significant proportion of the nests on Cavalos (during the nest census described in chapter 1, we reported on average 25 nests a day, but in some days, we recorded more than 40 nests), would require a large team and also a lot of nets. All of these would have to be transported to the island in boats. Another concern when using nets to protect the nests is that if they are left for the entire incubation period, they might influence the magnetic field felt by the hatchlings, which might disorient them on the beach. (Irwin, 2003), so, a nonferrous material like aluminium should be used. Nets could probably be used efficiently on other islands in the Bijagós where nesting activity occurs on a very small scale (Catry et al., 2009). But even in these islands, a cage-like design would probably be more efficient than just a net on top of the nests.

An alternative to metal nets would be the use of cheaper and lighter plastic mesh nets, which were effective preventing predation from foxes (Kurz et al., 2011) and to a lesser extent from varanid lizards in Australia (Lei and Booth, 2017). However, the addition of plastic material on a natural nesting ground has obvious environmental concerns, and if the net is lost or damaged, it might trap turtle hatchlings and other wildlife. Furthermore, erosion of plastic materials creates microplastics, which are a hazard to sea life, including sea turtles (Lusher, 2015).

Erasing the tracks and signs of sea turtle activity might reduce predation rates by making the nests harder to find although it did not fully prevent the lizards from identifying them. If, as our false nests experience suggests, the lizards rely mainly on chemosensory signals to identify a predated nest, it is expected that this method will not be very effective as a management option. We should however consider that revolving the sand might spread the fluids released by the turtle during oviposition which are a strong scent cue for most sea turtle nest predators (Oddie et al., 2015) which means that it will not be only visual cues that are masked with this, but some scent

cues as well. It has been reported that some predators rely partially on visual cues to detect turtle nests (Oddie et al., 2015), so, this method might make the nests harder to detect, forcing predators to spend more time searching for them, but not preventing them from finding the nests.

Using scent to mask nests lead to some reduction in predation rates, although it was not statistically significant. As varanid lizards have a very acute sense of smell and use chemosensory cues in prey detection (Cooper, 1989), it is expected that scent masking the nests is an effective method to reduce their detectability. This is further corroborated by our false nests experiments when we saw that only the false nests with eggs were predated even though there were no visual cues. Furthermore, more than 75 % of natural predation usually occurs when the nests are less than 1 week old (Ferreira 2012; Leighton et al., 2009), and sometimes, all nile monitors may concentrate all their predatorial activity in first days of the nests existence and afterwards the surviving nests may remain intact for all the nesting season (Cruce, 2009). The predation timings which also helps support the theory that the lizards rely mainly in scent cues as the nests remain visible for much longer than a week, while the scent, especially in areas like Guinea-Bissau where the turtle breeding season coincides with the rainy season (Catry et al., 2010), is probably washed away quickly. However, when predation by ghost crabs is high, the tunnels they open in the turtles- nests may cause scent cues to be released, increasing the likelihood of them being predated by other animals (Barton and Roth, 2008)

When we analysed the artificial nests experiments, we saw that only the man-made nests suffered predation (7 out of 32 nests (22%) were predated). When comparing this value with the false nests where no predation occurred, we see a statistically significant difference. These results seem to suggest that lizards rely mainly on scent cues to forage for turtle eggs and that visual cues such as revolved sand might only play a secondary role. Additionally, it seems that the most important cue they use is not the scent of the turtle but the eggs and the secretions the turtles produce when laying them.

An active forager like the nile monitor is an animal that is expected to rely strongly on scent cues to detect prey (Cooper, 1989). These lizards are tongue flicking lizards, which means that they have a very acute sense of smell which they use to scout their surroundings in their search for preys (Cooper, 1989).

This makes the scent treatment the strongest candidate of the three to be used as a management tool in dense rookeries. Besides being a technique adapted to the behaviour of the lizards, it is also the cheaper (for our experience, we had to spent 40 euros to protect 28 nests) and least time consuming one (while it took less than a minute to sprinkle the clove essence solution each nest, the net and track erasing techniques took more than 15 minutes for each). Additionally, this technique does not require the disturbance of the turtles' habitat, so it can be used even in sensible areas such as small dunes. There is still a lot of testing required before applying this technique in a larger scale in order to find out what is the most efficient compound to be used and how much deterrent should be applied on each nest. However, given that varanid lizards in general are highly intelligent and are able to learn from association with a stimulus where profitable prey can be found (Firth et al., 2003; Kaufmanso et al., 1996). In order to avoid having them using the scent mask as a cue to where nests are (which would defy the propose of protecting them), it might be appropriate to change the scent mask used frequently.

However, we should bear in mind that as in this study not all the nests were treated, so the treatments might just have diverted the predators to other, easier to find, nests. So, if all the nests were treated the lizards might just start spending more time searching for the nests and the

overall predation rate would be the same. To find out if this happens, further research should be done comparing predation rates in all the nest before and after protecting a percentage of the island nests.

Final Remarks:

With this study, we showed that Cavalos has some importance for the sea turtle population of PNMJVP. There is an inverse relation between the degree of religious protection each island is subject to and the number of sea turtles; João Vieira, the least sacralised island (Catry et al., 2009), is the one where the smallest amount of sea turtles nest, despite being the largest of the studied islands (IUCN, 2002); Poilão, the most sacred island to the Bijagós being the one with more turtles present (Catry et al., 2010). This means that the remarkable conservation of traditional rituals and religions of the Bijagós (Cross, 2014) helped maintaining the PNMJVP one of the largest nesting places for the green turtle in the World (Catry et al., 2010).

As stated in the first chapter, there is a strong concern with the viability of the island of Poilão in the future due to sea level rise and its small size (IUCN, 2002). One of the discussed alternatives is transferring of some nests from Poilão to the other islands of the Park (IBAP, 2017). When doing this, besides trying to dig the translocated nests under conditions similar to the original turtle nests to preserve the sex-ratio, there should be an attention to predation and flooding risk of the new nests when choosing their location. In Cavalos, based on this study, the safest area would probably be the high dunes, as the nests there would be built higher, be more protected from flooding, and away from the vegetation where predation risk is greater.

In the second chapter we showed that even in places with relatively high nest densities, it might be possible to conduct a relatively cheap method to protect sea turtle nests from nile monitor predation. As we said before, nets are very effective when used with mammal predators (Ratnaswamy et al., 1997; Yerli et al., 1997) but showed only limited efficiency with the lizards. The use of scent masks has only recently begun being investigated, so there is still limited data as to its efficiency (Lei and Booth, 2017). The use of visual masks so far as we could find out, has not been studied yet. New studies should focus on which scent mask may be the most cost-effective, thus enabling this method to be used in large scale as an alternative nest protection technique.

With this study, more light has been shed on the turtles of PNMJVP. Further studies should be performed in the islands of Cavalos and Meio, where there is less information about these animals to determine if the number of sea turtle nests recorded on Cavalos was close to the average or if this study occurred during an abnormal nesting season. It would also be very interesting to make further tagging efforts to ascertain how do the turtles use each island and if there are different subpopulations nesting on each island.

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(Acording the citation rules of the journal "Biological Conservation")

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Annexes:

Table A.1: Correlation between the possible variables to be used in the binomial regression made in the first chapter. The regression tested potential effects on the predation probability by the nile monitors on sea turtle eggs in the island of Cavalos. We tested correlation for the distance to the island vegetation, distance to the sea, habitat of the nests and location (E/W) of the nests on the island. Strong correlations (P-value <0.01) are singled in bold.

Correlations					
		Distveg	Distsea	Habitat	Location
Distveg	Correlation Coefficient	1			
	Sig.	-			
	N	64			
Distsea	Correlation Coefficient	0.008	1		
	Sig.	0.95	-		
	N	64	64		
habitat	Correlation Coefficient	-.316	-0.098	1	
	Sig.	0.011	0.443	0	
	N	64	64	64	
Location	Correlation Coefficient	**.409****	0.078	**-.581**	1
	Sig.	**0.001**	0.542	**0**	.
	N	**64**	64	**64**	64