Marine Pollution Bulletin 137 (2018) 481–487

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Marine debris as a barrier: Assessing the impacts on sea turtle hatchlings on their way to the ocean

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ARTICLE INFO

Keywords:
Cape Verde
Caretta caretta
Conservation
Crawl time
Marine litter
Threatened species

ABSTRACT

Marine debris is dispersed worldwide and has a considerable impact on biodiversity. In this study, the effect of marine debris on the time needed for hatchling loggerheads to reach the ocean once they have emerged from the nest was investigated. After a preliminary census of marine debris on different beaches of Boa Vista Island, Cape Verde, a field test was carried out with four different scenarios: low density marine debris, medium density marine debris, high density marine debris, and a control scenario. The time that hatchlings required to cross the different scenarios was recorded (n = 232). The results showed that crawl times were affected by the different marine debris scenarios, with the "high density" scenario specifically showing a significant difference from the control, low density and medium density scenarios. This study provides information on the risks of marine debris for hatchling sea turtles and provides conservation recommendations to reduce this potential risk.

1. Introduction

Marine debris is a severe problem that impacts not only wildlife (Gall and Thompson, 2015; Kühn et al., 2015) but also human health, the marine environment and the economy. The distribution, abundance, typology and source of marine debris have been widely studied around the world (Galgani et al., 1995; Whiting, 1998). Additionally, its impact on biodiversity has been evaluated and studied by researchers around the world over the last decades, e.g., in birds (Azzarello and Van-Vleet, 1987), cetaceans (Baulch and Perry, 2014), manatees (Beck and Barros, 1991) and seals (Baird and Hooker, 2000; Allen et al., 2012). The Convention on Biological Diversity (Secretariat of the Convention on Biological Diversity and the Scientific and Technical Advisory Panel-GEF, 2012) recognizes the urgency of action in order to prevent and mitigate the impacts of marine debris on biodiversity.

The main consequences of marine debris on biodiversity are entanglement (Mann et al., 1995; Gregory, 2009; Wilcox et al., 2016), ingestion (Pettit et al., 1981; Pierce et al., 2004) and chemical contamination (Rochman et al., 2013; Koelmans, 2015). Specifically, the presence of microplastics is an increasing threat for marine fauna, because they can enter the food web through ingestion, as has been observed in sea birds, crustaceans and fish (Cole et al., 2011; Lusher, 2015). In addition, litter contributes to the dispersion of invasive species that are attracted to the freely floating marine debris (Gregory, 2009). Sea turtles are one of the marine species most affected by both entanglement (López-Jurado et al., 2003; Casale et al., 2010) and debris ingestion (Bjorndal et al., 1994; Bugoni et al., 2001; Santos et al., 2015), with five of the seven species of turtles on the species list for which the greatest number of documents/papers have reported entanglement or ingestion (Secretariat of the Convention on Biological Diversity and the Scientific and Technical Advisory Panel-GEF, 2012). Taking into account that multiple populations of six out of the seven species of sea turtles are considered threatened (i.e., critically endangered, endangered or vulnerable by the International Union for the Conservation of Nature - IUCN, 2018), special attention needs to be paid to marine debris and its effects on sea turtle populations.

In sea turtles, marine debris effects have been mostly studied in adults, but marine debris can also have an effect on hatchlings in several ways: altering the nest properties and consequently shifting the hatchling sex ratios (Carson et al., 2011), preventing them from leaving the egg chamber as it acts as a barrier within the sand column (Nelms et al., 2015), or being an impediment to the hatchlings trying to reach the ocean once in the sand (Özdilek et al., 2006; Triessnig et al., 2012). The time a hatchling spends on its way to the ocean is a crucial moment to the survival of sea turtles. They typically emerge from their nest at

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https://doi.org/10.1016/j.marpolbul.2018.10.054
Received 17 June 2018; Received in revised form 15 October 2018; Accepted 26 October 2018
0025-326X/

night (Demner, 1981) and crawl seaward, swimming away from shore during a 24–36-h period called a frenzy period (Wyneken and Salmon, 1992). The more time they spend crawling to the sea, the more time they are exposed to predators as well as the higher probability they could die due to exhaustion once in the sea (Kraemer and Bennett, 1981; Witherington and Martin, 2000; Bourgeois et al., 2009; Tomillo et al., 2010). Many anthropogenic activities (e.g., light pollution, tyre ruts) may increase this time, causing disorientation, predation, and exhaustion (Witherington and Bjorndal, 1991; van der Merwe et al., 2012; Triessnig et al., 2012). Although marine debris can increase this time and consequently impact the hatchling survival, not too much attention has been paid to this issue so far. Only a few previous studies have been carried out regarding marine debris and hatchling crawl (Özdilek et al., 2006; Triessnig et al., 2012), but this is the first attempt to design a study replicating various scenarios (i.e., marine debris distribution, density and typology) detected in the field. We have developed an in situ experiment taking into account the situation we have found in Boa Vista Island, Cape Verde. Additionally, this study was developed in a remote and isolated area, showing that the presence of marine debris on beaches is not only a problem in habited coastlines but also on isolated islands, where debris can arrive via wind and tidal currents (Barnes et al., 2009; Santos et al., 2009). In remotes areas, such as the Cape Verde Islands, for example, most of the marine debris comes from fishing activities (e.g., boats). This finding reflects the importance of also studying the impact of marine debris in isolated and fragile scenarios.

The current study involved the development of an experimental study based on previous field marine debris monitoring work on an isolated island. With the experimental study, we examined the effects of marine debris on the time needed for hatchling loggerheads (*Caretta caretta*) to reach the ocean once they had emerged from the nest. The results of this study provide information on the risks of marine debris for hatchling sea turtles and provide conservation recommendations to reduce this potential risk.

2. Methods

2.1. Study site

The Boa Vista Island (16° 06′ 12″ N; 022° 48′ 13″ W) is the easternmost island of the Cape Verde archipelago (Fig. 1). The archipelago hosts the third most important loggerhead sea turtle nesting rookery in the world and the second in the Atlantic. Specifically, Boa Vista hosts 85–95% of the archipelago population (López-Jurado et al., 2007; Marco et al., 2010, 2012), and it is where > 10,000 nests are laid every year (López-Jurado et al., 2007; Marco et al., 2010, 2012). This study was conducted on Reserva Natural das Tartarugas (RNT) on the southeast coast of the island (Fig. 1), a 25-km span of inhabited beaches. Hatchlings were obtained from a hatchery situated at Ervatão beach that has been operating since 2005 under the control of the Cabo Verde Natura 2000 NGO.

2.2. Preliminary study

A preliminary study of several beaches on Boa Vista Island was conducted in August 2014 to determine the presence, distribution and characteristics of marine debris on Boa Vista beaches. This allowed us to develop a field-based experimental design. The goal of this preliminary study was to determine the number, density, typology and dimension of marine debris encountered by a hatchling on its way to the sea. We chose three sampling beaches at Boa Vista Island: Calheta do Pau, Laiedo Texeira and Nho Martin. At each site, rectangle transects (25 m long and 1 m wide) were sampled between the line of high tide and another line near the border of the dunes, in order to cover the space a turtle uses when leaving the beach. The number of transects in each site depended on the dimension of the beach. The total area sampled was 150 m^2 in Calheta do Pau (6 transects), 150 m^2 in Laiedo Texeira (6 transects) and 250 m^2 in Nho Martin (10 transects). Surveys were performed by two people. Each transect was delimited and covered once to count and classify the objects. Only the visible marine debris on the surface was surveyed. Once we found an item, it was measured (length, height, width) and classified into one of the following categories, taking into account the classification used by the Ocean Conservancy and adapting it to the items likely to be found in

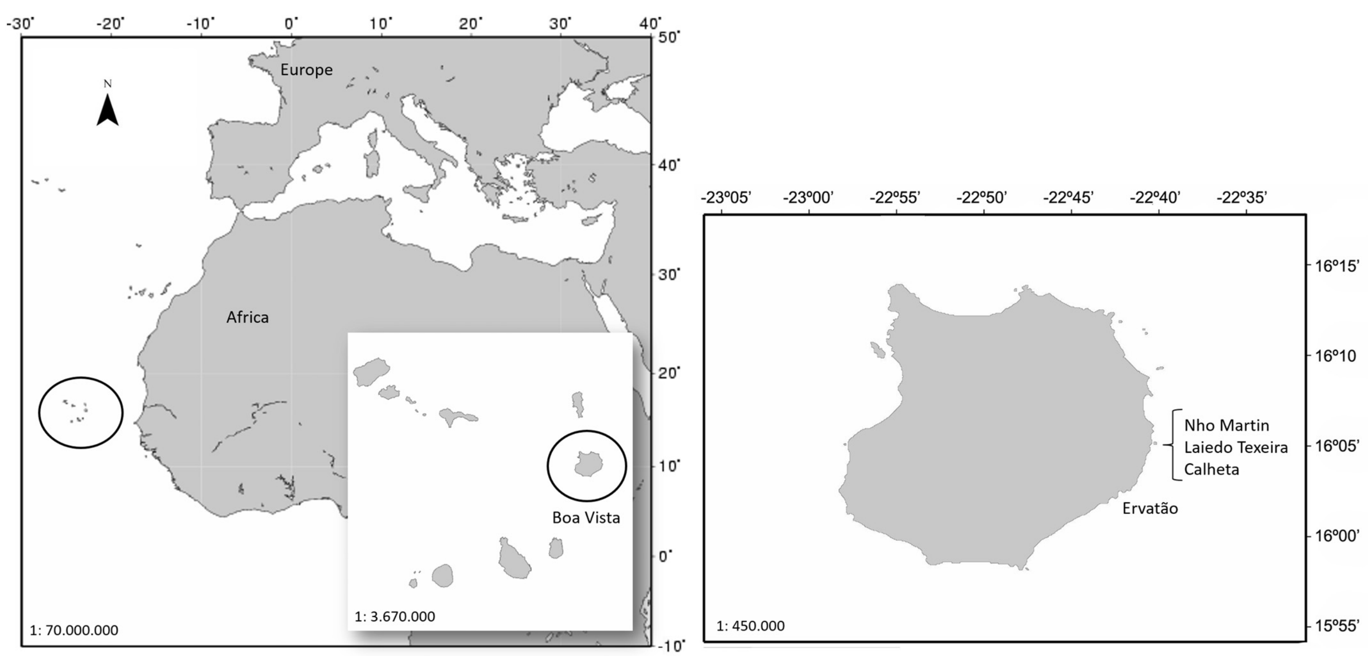
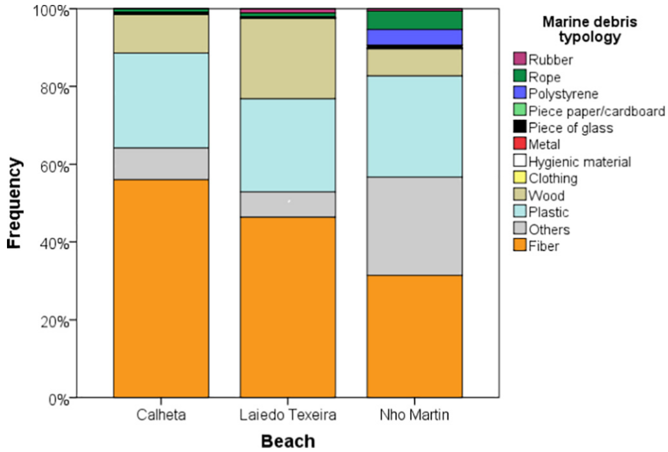


Fig. 1. Location of Boa Vista Island in the western coast of Africa. The three beaches from the preliminary study are located on the southeast coast of the island (Reserva Natural das Tartarugas).

Table 1
Preliminary study results. Main data of marine debris found on the three beaches.



Cape Verde beaches: glass, metal, paper and cardboard, carton, polystyrene, wood, fabric, rubber, plastic, synthetic material, hygienic/sanitary, fishing nets and others. The exactly type of debris was also recorded. Additionally, the orientation of items was measured. We registered the orientation of each item relative to the sea, taking into account the position of the open part of the item, with 0° meaning the open part was oriented straight to the sea. Orientations from 0 to 315° were registered. Then, the item was removed from the transect to avoid double counting.

2.3. Marine debris experimental study

2.3.1. Experimental design

To test the effects of marine debris on the time needed for a hatchling to reach the ocean, we carried out a field test designed from the preliminary study results (see "Preliminary study"). According to the results of the preliminary study (Table 1), four scenarios with different densities of marine debris were designed: low, medium and high density marine debris, and one more scenario that acted as a control. The number of items for each scenario was selected by calculating the 50th, 75th and 95th percentiles of the amount of marine debris detected on the transects of the preliminary study, pooling together the three beaches. As a result, the scenarios presented this abundance of items: low density marine debris (50th percentile; 9 items), medium density marine debris (75th percentile; 20 items), high density marine debris (95th percentile; 45 items), and control scenario (no items). The typology of items represented in each scenario followed the proportions of different items found in the preliminary study (Table 2). The size and orientation of items for the experiment were the mean size and mean orientation per item detected in the results of the preliminary study (Table 2).

For each scenario, a 15 × 0.5-m path was constructed perpendicular to the shoreline to simulate a route from the nest to the sea. The paths were constructed close to the hatchery in order to facilitate access to the individuals. First, the land was cleaned of large stones and levelled out to homogenize the conditions across treatments. Then, the paths were constructed using 10-cm high wood sticks, which separated one treatment from the next. Finally, the four treatments were created by laying the different marine debris items on the paths according to the four different scenarios (Fig. 2; Table 2).

2.3.2. Data collection

Data collection was conducted in September 2014 in Ervatão Beach (Boa Vista Island, Cape Verde). The hatchery was checked continually late in the afternoon. After an emergence took place in each nest, we randomly collected 12 hatchlings from each and divided them equally among the 4 scenarios (low, medium and high density of marine debris and control). The hatchlings were released at the starting point, and the time it took them to crawl along the paths was recorded. A light was situated at the end of each treatment to orient the sea turtles along the paths. When a hatchling spent > 20 min attempting to get through the path, the turtle was released and the time was recorded as $t = 1200$ s. Once the trail was finished, the righting response time (time needed to flip over) was calculated by taking the mean of three consecutive righting times recorded for each turtle. Then, the hatchling was measured (straight carapace length, straight carapace width) using a caliper (accurate to the nearest 0.1 mm) and weighed using a microbalance (to the nearest 0.1 g), and the data were recorded. Finally, the hatchlings were released into the sea as soon as all of the data had been collected.

2.4. Statistical analyses

In our statistical analyses, we aimed to detect the effects of the presence of marine debris on the time it takes hatchlings to travel from their nest to the ocean. After testing all dependent variables for normality, we used generalized linear models (GLMs) with gamma errors and identity link function to test the time it took the turtles to reach the sea. Different factors were tested: marine debris scenario (low, medium or high density marine debris and control), nest, length and weight of the turtles. We looked for the most parsimonious of the full models by comparing the Akaike Information Criteria (AIC). The data analysis was performed using IBM SPSS Statistics 21 software, and statistical significance was assumed at $P < 0.05$.

3. Results

In total, 232 turtles from 20 nests were tested, from which 181 successfully completed the route (78.02%) and 51 (21.98%) were considered not valid either due to disorientation or exceeding the maximum time allowed (20 min). The mean carapace length (SCL min) was 41.97 ± 4.19 mm, and the mean carapace width (SCW) was 32.40 ± 1.58 mm. The mean hatchling weight was 16.65 ± 2.28 g.

The most predictive model (with smallest AICc) of the generalized linear models (GLMs) indicated that crawl times were affected by the marine debris scenario, nest and weight, indicating that the quantity of debris, the carapace individual width and the nest a hatchling comes from significantly impact the time needed to reach the ocean (Table 3, Supplement 1, Fig. 3). Specifically, a post hoc analysis showed that crawl times of scenario-3 were significantly different than those of the control ($P = 0.001$), scenario-1 ($P = 0.000$) and scenario-2 ($P = 0.001$). In regard to biotic variables, although hatchling carapace length and weight were also tested, the carapace width was slightly more relevant in explaining crawl times (Supplement 1).

When we analysed the righting response time, we found that the most predictive model was the one that included the marine debris scenario and the carapace individual length (Table 3, Supplement 1).

4. Discussion

Our results show that the presence of marine debris on sea turtle nesting beaches increases the time that hatchlings need to reach the ocean. In our experimental study, we tested three different marine debris scenarios (low, medium and high density) with a marine debris density of 1.2, 2.67 and 6 items per m^2, respectively, and showed that the high density scenario significantly increases crawl time. The time a hatchling spends reaching the ocean determines its probability of being predated by birds, ghost crabs and others animals (Tomillo et al., 2010; Burger and Gochfeld, 2014). In addition, the more time spent crossing the beach, the less energy the hatchlings have to swim away from shore, where the predation rate declines (Kraemer and Bennett, 1981; Gyuris,

Table 2
Experimental design details. Three scenarios (apart from control) were tested: low density, medium density and high density. The table shows the number, size and distribution of items contained in each scenario, as well as the orientation of each (1: 45–225°; 2: 90–270°; 3: 125–315; 4:180–360°).

					Marine debris scenario														
					Low density					Medium density					High density				
Marine debris typology	N° of items per transect (mean)	Length (cm) (mean)	Width (cm) (mean)	Height (cm) (mean)	Number of items	Orientation				Number of items	Orientation				Number of items	Orientation			
						1	2	3	4		1	2	3	4		1	2	3	4
Ropes	21.70 ± 13.90	18 ± 32	1 ± 5	3 ± 1	4	1	2	–	1	7	2	2	1	2	12	3	4	2	3
Sea turtle bones	6.00 ± 6.89	13 ± 9	6 ± 3	2 ± 2	–	–	–	–	–	1	–	1	–	–	6	1	3	–	2
Wood	5.59 ± 4.96	22 ± 23	5 ± 4	2 ± 3	1	–	–	1	–	2	–	1	1	–	5	1	1	2	1
Cuttlebone	7.50 ± 8.42	13 ± 6	7 ± 2	2 ± 2	–	–	–	–	–	1	–	–	–	1	5	1	1	1	2
Bottle	3.65 ± 3.69	23 ± 8	10 ± 7	6 ± 3	1	–	1	–	–	2	–	1	1	–	3	1	1	1	–
Piece of plastic	4.65 ± 3.03	12 ± 16	5 ± 7	2 ± 6	1	–	1	–	–	1	–	1	–	–	3	1	1	1	–
Bunch of ropes/nets	3.50 ± 2.20	28 ± 45	10 ± 13	6 ± 4	1	–	1	–	–	2	–	2	–	–	2	–	1	–	1
Others	3.00 ± 1.25	12 ± 127	8 ± 13	3 ± 4	1	–	1	–	–	1	–	1	–	–	2	1	1	–	–
Plastic Strapping	2.00 ± 1.50	39 ± 94	1 ± 7	1 ± 0	–	–	–	–	–	1	–	–	–	1	1	–	–	–	1
Unique fishing net	2.00 ± 1.24	21 ± 35	7 ± 8	2 ± 3	–	–	–	–	–	1	–	1	–	–	1	–	1	–	–
Cap	2.14 ± 1.17	3 ± 2	3 ± 1	1 ± 1	–	–	–	–	–	1	–	1	–	–	1	–	1	–	–
Plastic bag	1.25 ± 0.62	15 ± 58	8 ± 6	3 ± 5	–	–	–	–	–	–	–	–	–	–	1	–	1	–	–
Buoy	1.80 ± 1.30	13 ± 3	12 ± 3	6 ± 4	–	–	–	–	–	–	–	–	–	–	1	–	1	–	–
Polyurethane foam	1.50 ± 0.58	8 ± 2	5 ± 3	3 ± 1	–	–	–	–	–	–	–	–	–	–	1	–	1	–	–
5 l container	1.56 ± 0.73	28 ± 6	19 ± 5	11 ± 4	–	–	–	–	–	–	–	–	–	–	1	–	–	–	1

1994). Given that only 1 in 1000 sea turtle eggs is estimated to hatch and reach maturity (Frazer, 1986), these results reveal the importance of applying management measures in nesting sea turtle beaches in order to assure a higher hatchling survival.

Hatchling crawl to the beach can be affected both by natural causes (Stancyk, 1982; Marco et al., 2015) and man-induced causes via the use of off-road vehicles (Lamont et al., 2002; van der Merwe et al., 2012), light pollution (Witherington and Bjorndal, 1991) or, as we show in this work, marine debris (Triessnig et al., 2012). Some studies have shown that tyre ruts may delay a hatchling sea turtle's ability to reach the ocean, but they can also disorient hatchlings (Van der Merwe et al., 2012, Aguilera et al., 2018). Additionally, light pollution can cause disorientation, which can translate into more time needed to escape from the nearshore zone, where higher probabilities of being predated upon are found (Harewood and Horrocks, 2008).

Previous studies have focused on the effects of individual items on the time it takes hatchlings to reach the ocean. Triessnig et al. (2012) conducted an experiment on marine debris barriers in which they tested different item categories separately (plastic bottles, styrofoam cups, plastic canisters and fishing nests). In our study, we aimed to go further by designing a field-based situation in which we simulated three different scenarios likely to be encountered by a hatchling, and in which we took into account the typology, density, and orientation of marine debris based on a previous field camp study. The idea was to simulate the most realistic situation a hatchling can face. Additionally, whereas previous studies provided information on how marine debris affects the dispersion of hatchlings at touristic and non-isolated beaches (Özdilek et al., 2006), here we present a study on isolated beaches that proves that also in these cases the presence of marine debris affects the time a hatchling needs to reach the ocean, as well as not allowing them to reach the ocean in some instances.

Measures to decrease the marine debris occurrence in beaches worldwide have been developed throughout the last years (including specific legislation, coastal cleanups, and educational awareness campaigns), but more specific effort is needed. So far, marine debris regulations have been promoting the conservation of the world's oceans, such as the 1972 Convention on the Prevention of Marine Pollution by Dumping Wastes and Other Matter (the London Dumping Convention

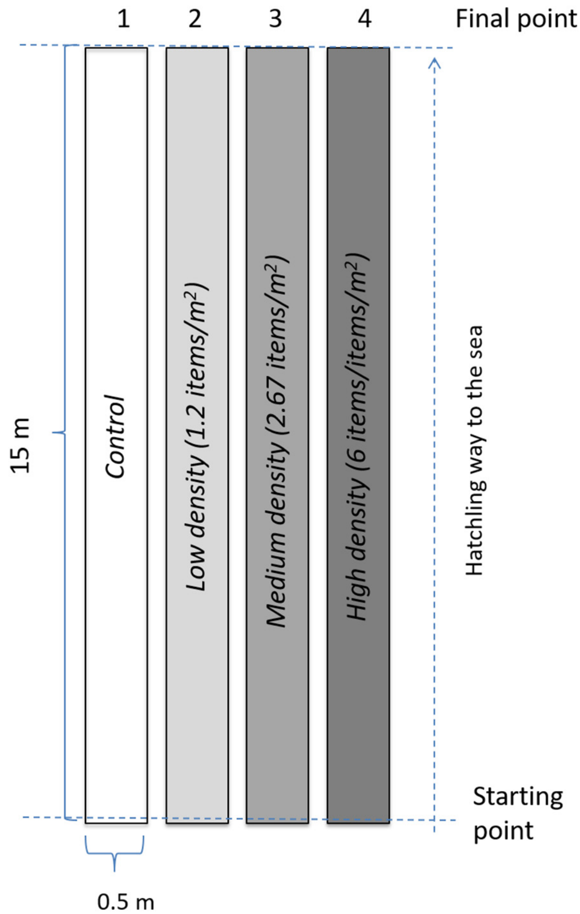


Fig. 2. Experimental design diagram showing the four different scenarios tested: control, low density (9 items; 1.2 items/m^2), medium density (20 items; 2.67 items/m^2) and high density (45 items; 6 items/m^2).

Table 3
Most parsimonious generalized linear models to test the effect of marine debris scenarios and biological factors (nest, length, width, weight) on time needed for hatchlings to reach the ocean (crawl time) and time to flip over (righting response time). The expected direction of response to each continuous variable is given for each variable (Beta coeff.).

Dependent variable	Model	AICC	Factor	Beta coeff.	Wald chi-square	d.f.	*P*-value
Crawl time	Scenario + Nest + Width	2201.608	Scenario	_	19.984	3	0.000
			Nest		110.619	19	0.000
			Width		4.866	1	0.027
Righting response time	Scenario + Length	1065.619	Scenario	_	9.749	3	0.021
			Length		21.931	1	0.000

or LDC) and the 1978 Protocol to the International Convention for the Prevention of Pollution from Ships (MARPOL, Annex V) (Ninaber, 1997; Clark, 1997; Derraik, 2002). Nevertheless, no signs of recovery have been observed in this sense, with one of the reasons being that under MARPOL Annex V, the on-board waste management discharge of most wastes except plastics was allowed for many years (National Research Council, 2008). Fortunately, measures to improve the situation have been taken, and the revised Annex V (2013) prohibits the discharge of all garbage into the sea, except as provided otherwise. However, more national and international measures need to be implemented, as well as the ones that go behind the "Zero Waste" management strategies.

Waste management on islands is a serious problem as the limited territory makes the collection, transportation, storage, treatment and disposal of waste more difficult (Santamarta et al., 2014). In addition, for Small Island Developing States (as Cape Verde), this problem is even worse, as they have a rapidly increasing waste generation (e.g., increasing tourism activities), lack of economic resources and poor expertise in the field of waste management (Mohee et al., 2015). In the

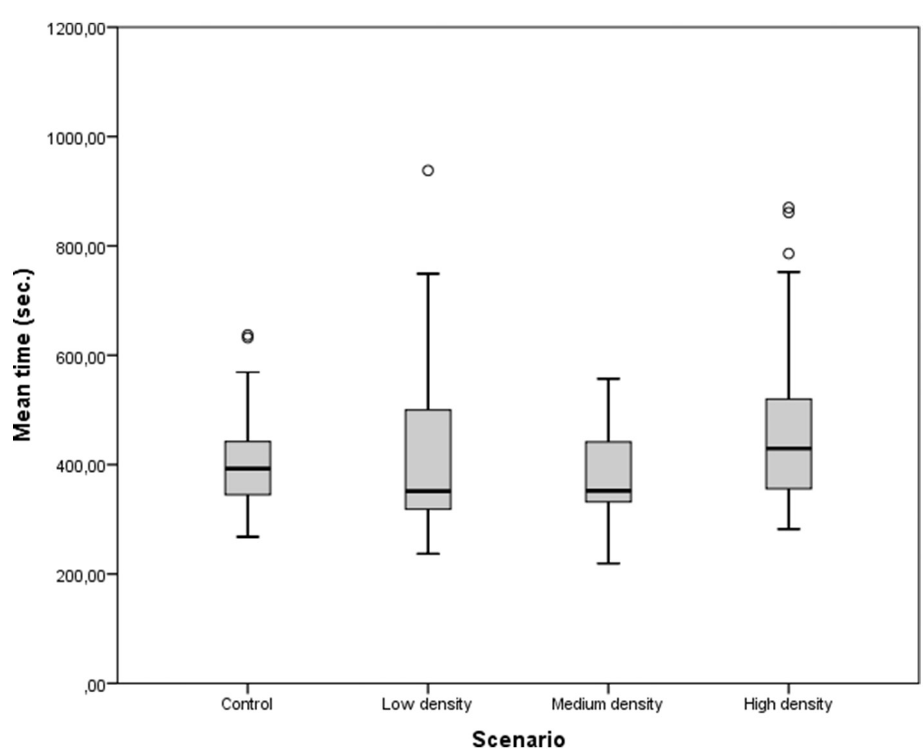


Fig. 3. Mean (± standard error) time (*sec*) spent for loggerhead sea turtle hatchlings to complete the different scenarios: low density, medium density, high density, and control.

case of Cape Verde, the project "Waste Roadmap of Cabo Verde" started in 2014 in order to build a National Waste Management Strategy (PENGeR) that was approved by the Council of Ministers on 2nd March 2016 (Annex to Decree-Law no. 32/2016 of 21st April). After that, 5 Operational Plans were developed for 5 islands, but Boa Vista was not included. Thus, more efforts are needed for the implementation of this National Waste Management Strategy. Nevertheless, is important to highlight the fact that our study site is remote (with no close population or touristic infrastructures) and still has a high density of marine debris, which means that most of the litter has an external origin. Therefore, more efforts are needed on the management of marine debris, not only on land but also at sea and at the different potential source locations.

One of the initiatives that are carried out to manage marine debris is beach cleanups. Although coastal cleanups are being carried out on many beaches worldwide these days (Ocean Conservancy, 2016), they should be done before the hatching season according to the season in each rookery. This would help lower or eliminate the accumulation of marine debris for the nesting season, but daily check surveys should be done in addition to this in touristic beaches where there are more possibilities of finding marine debris. In addition, environmental citizen involvement should be promoted in order to make citizens aware of the biology of sea turtles and their nesting process and aware of the importance to maintain clean beaches for their survival and for a globally healthier environment, as well as the culture of "Zero Waste" educational campaigns. These campaigns are especially important in places where sporadic nesting events have been increasing over the last few years.

These measures should be complemented with a deeper knowledge about marine debris. As some authors have suggested, a world-wide database of marine debris surveys in sea turtle nesting beaches would help improve the knowledge about the impacts of plastics (and other types of debris) on sea turtles (Nelms et al., 2015) and therefore would facilitate the commencement of measures to manage the problem. In this sense, some initiatives have been developed, e.g., Marine LitterWatch (European Environment Agency, 2013), which is a mobile app developed by The European Environment Agency that gathers information and data about marine litter and allows for the tackling of marine debris, thereby strengthening Europe's knowledge base and providing support for European policy making. Nevertheless, taking into account that marine debris is a global concern, more international initiatives involving as many countries as possible should be developed.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2018.10.054.

Acknowledgements

This research was conducted with the support of the Marine Turtle Conservation Fund (MTCF) – US Fisheries and Wildlife Service (NOAA, EE.UU) (Grant # F14AC00213), and the authors are grateful to the Ervatão Field Camp assistants and volunteers (NGO Cabo Verde Natura 2000) who assisted in collecting data. The authors utilized the Maptool programme (http://www.seaturtle.org/maptool/) for the drawing of the figures.

All applicable international and institutional guidelines for the care and use of animals were followed.

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