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Ingestion and defecation of marine debris by loggerhead sea turtles, *Caretta caretta*, from by-catches in the South-West Indian Ocean

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ABSTRACT

Marine debris, caused by anthropogenic pollution, is a major problem impacting marine wildlife worldwide. This study documents and quantifies the ingestion and defecation of debris by 74 loggerhead sea turtles, *Caretta caretta*, in the South-West Indian Ocean. Debris was found in 51.4% of gut or fecal samples of loggerheads by-catch from Reunion Island long liners. Anthropogenic debris was ubiquitous in our samples with plastics accounting for 96.2% of the total debris collected. No significant relationship was detected between the characteristics of ingested debris and the biometric characteristics of loggerheads. The number, weight, volume and mean length of debris were higher in gut content of deceased loggerheads than in fecal samples of live turtles, but not significantly, except for the mean length. This is the first record of debris ingestion by sea turtles in the Indian Ocean and our results highlight the magnitude of this pollution of the marine environment.

1. Introduction

The pollution by marine debris and more specifically by anthropogenic debris is a major threat to marine environment. Negative impacts on marine life is an increasing problem as manufactured solid wastes, such as plastics can persist from decades up to centuries in the environment (Gregory, 1978; Gorman, 1993; UNESCO, 1994). In addition, the production of plastics has risen rapidly worldwide these last decades. Since 1950, the global production of plastics has roughly increased by 9% annually, and 280 million tons of plastics were produced in 2011 (PlasticsEurope, 2012). A significant quantity of man-products and plastics end up at seas and in oceans due to enhanced plastic demands and consumption and poor waste management policy and practices (Thompson et al., 2009; Andrady, 2011). As a result the amount of plastics has significantly increased on the ocean surface over the last three decades (Derraik, 2002; Barnes, 2005). Plastic litter has exponentially increased in remote marine environments between 1980 and 1990 (Ryan and Moloney, 1993). Contamination by plastics concerns all marine habitat types, from sedimentary zones to pelagic realms (Thompson et al., 2004; Barnes et al., 2009). Marine biodiversity is globally affected by the invasion of anthropogenic debris like plastics (Laist, 1987; Barnes, 2002). Numerous marine species, especially sea turtle, are prone to ingesting anthropogenic marine debris (Derraik, 2002; Schuyler et al., 2013) but the impact of this pollution is poorly studied.

The ingestion of anthropogenic debris by sea turtles can have negative effects on individuals and may ultimately precipitate death. The sub-lethal effects due to debris ingestion are difficult to detect and are likely to be more frequent than lethal effects (National Research Council, 1990). They encompass dietary dilution which leads to reduced nutrient absorption (McCauley and Bjorndal, 1999) and absorption of toxins (Bjorndal, 1997) that could impact negatively on growth rates, fecundity, and survivorship. However, asserting and proving a turtle death was attributable to the ingestion of marine debris may be difficult (Laist, 1987; Bjorndal et al., 1994; Tomás et al., 2002). There is indeed a low predictability of such mortality as the death generally occurs when the digestive tract is obstructed (e.g. Bjorndal et al., 1994; Bugoni et al., 2001; Lazar and Gračan, 2011). Although even small amounts of marine debris may cause these lethal effects, death is not systematic following the ingestion of debris. Large quantities of debris can remain in the gut for months (Lutz, 1990) and pass through their entire digestive tract without causing any lethal damage.

The loggerhead sea turtle, *Caretta caretta,* demonstrates great tolerance of anthropogenic debris ingestion and the species is generally able to defecate these items (e.g. Balazs, 1985; Casale et al., 2008; Frick et al., 2009; Present study). However, studies that

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have attempted to analyze in detail the anthropogenic debris found in fecal samples collected from live sea turtles are uncommon; most studies have enumerated anthropogenic debris solely from necropsied sea turtles found stranded (Bjorndal et al., 1994; Bugoni et al., 2001; Tourinho et al., 2010; Lazar and Gračan, 2011; Schuyler et al., 2012; Campani et al., 2013), or from illegal and incidental captures (i.e. by-catch fisheries) (Tomás et al., 2002; Lazar and Gračan, 2011). Analyzing and comparing both necropsies and fecal samples offer an opportunity to provide insights into the potential effects of anthropogenic debris on loggerhead's survival, and the partial or total digestion process of anthropogenic debris.

The loggerhead sea turtle is listed as an Endangered species in the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (IUCN, 2013); this species is subjected to a growing number of anthropogenic threats at all life stages (Hutchinson and Simmonds, 1992; Bolten et al., 2011), and is particularly at risk of ingesting marine debris. Marine debris can be mistaken for food mainly because loggerhead turtle shows evidence of complex life stages and forages opportunistically on preys (Witzell and Teas, 1994; Lutcavage et al., 1997). There is a growing documentation on the occurrence of anthropogenic debris in loggerheads, and the populations worldwide are likely to be affected by this threat through entanglement or ingestion. For instance, studies reporting marine debris ingestion by this species have been documented around the world, in the Mediterranean Sea (Tomás et al., 2002; Casale et al., 2008; Lazar and Gračan, 2011; Campani et al., 2013), in the Atlantic Ocean (Plotkin et al., 1993; Bugoni et al., 2001; Frick et al., 2009) and in the Pacific Ocean (Parker et al., 2005; Boyle and Limpus, 2008). These studies demonstrated that plastic was the most frequently ingested anthropogenic debris. However, no information concerning ingestion of anthropogenic debris by sea turtles in the Indian Ocean was found in the literature. There is a lack of information evaluating the spread of anthropogenic debris in this basin and this type of information is limited to a few strandline surveys (Barnes, 2002, 2005). To our knowledge, the ingestion of debris by marine organisms in the South Indian Ocean has been reported uniquely on seabirds collected at sea off South Africa (Ryan, 2008).

In this context, evaluating and understanding the impacts of anthropogenic pollution on marine organisms in the Indian Ocean are necessary to adequately address conservation issues. Interestingly, this oceanic basin constitutes important migratory routes for loggerheads (Dalleau et al., in press) from a large nesting aggregation site of the Sultanate of Oman for tens of thousands of females per year (Ross and Barwani, 1995), and also from the Maputaland coast of South Africa where hundreds of females nest annually (Hughes, 1974a). Unfortunately, the ecology of loggerheads is poorly documented in this basin. More specifically, there is little specific information on the duration of the juvenile stage in the oceanic habitats although there is little doubt that hatchlings, juveniles and sub-adults spend many years in the oceanic zone. Furthermore, the duration of this oceanic period of juvenile loggerheads was found highly variable, for instance this duration was estimated to range between 6.5 and 11.5 years in the Atlantic (Bjorndal et al., 2000; Bolten, 2003).

The present study aims at documenting and quantifying marine debris ingestion and defecation of loggerhead sea turtles that have been accidentally caught in the South-West Indian Ocean by Reunion Island pelagic long-liners fisheries and rehabilitated at the health center of Kelonia. Numbers of captured loggerheads underwent surgical operations to remove deeply embedded fish hooks and some of these died. It was considered a possibility that those that died may have had a larger quantity of anthropogenic debris in their gastrointestinal tracts than those that survived the operations. For these reasons, a quantitative comparison was made between fecal and necropsied samples. We then describe patterns of ingested anthropogenic debris and explore the possible relationships between the biological characteristics of loggerheads and the anthropogenic debris collected.

2. Material and methods

From January 2007 to January 2013, 74 by-catch loggerheads were entrusted to Kelonia, the Reunion Island observatory responsible for the rehabilitation of injured sea turtles. All were collected in oceanic waters from the South-West Indian Ocean between Madagascar and Reunion Island. For some individuals, the geographical position of their capture was recorded by longliners fishermen, who typically fished in oceanic zones off the continental shelves (Fig. 1). For each individual the size (curved carapace length, CCL) and the weight were recorded (Fig. 2).

Surgical operations under anesthesia were performed on 73 loggerheads to remove fishing hooks and 72% ($n = 53$) of individuals had a full recovery. These turtles were rehabilitated, given appropriate treatment and kept under observation in separate tanks during at least three months with an examination at least six times per day. Upon defecation, feces were collected with a 0.5 mm sieve and analyzed for anthropogenic debris. For loggerheads that did not survive, necropsies were performed following the methods described by Wyneken (2001) and gut contents were analyzed. We obtained 21 gut content samples from 21 dead turtles, nine of which contained solid debris. Twenty-nine fecal samples were collected from 53 rehabilitated loggerheads; however six fecal samples were not available. The other 24 rehabilitated turtles did not release solid debris. Finally, out of 74 loggerheads, detailed analysis on anthropogenic debris ingestion was then performed on 32 individuals.

All anthropogenic debris longer than 0.5 cm were analyzed. Smaller debris was assumed to have resulted from fragmentation of larger pieces. Each debris item was weighed (to within 0.01 g) and its length (to within 0.1 cm) and volume (to within 0.1 ml) recorded. The total number, weight and volume was recorded. The mean length of debris was calculated for every gut content and fecal sample. Data were tested for normality (Shapiro–Wilk test) and homogeneity of variance (Levene's test). Log-transformation was performed on data that were not normally distributed and, if necessary, outliers were removed before statistical analyses.

The marine debris were also classified into three main categories that include the different types of debris found in this sample of loggerheads: (1) plastic debris (i.e. hard plastic, soft plastic, plastic caps), (2) fishing-related debris (i.e. line, rope, fishing stopper, polystyrene) and (3) miscellaneous debris (i.e. rubber, cloth/paper, tar, and natural marine debris such as seabird feathers, shells or natural woods). For each type of debris found we determined the total and relative abundance per individual ± standard error (s.e) (Table 2). In addition, we reported the number n_i of turtles that ingested a particular type i of debris and the frequency of occurrence F of each debris type:

$$F = (n_i/n) \times 100$$

where n is the total number of loggerheads for which debris information were available ($n = 32$).

Plastic items represented a significant higher proportion than the other categories of debris ingested, so we therefore analyzed the types of plastics (i.e. hard and soft plastic) in relation with the different colors of plastics (i.e. white, clear, blue, black and colored) in order to represent the mean percent of plastic types with colors found.

We analyzed the amount of debris ingested in terms of number, weight, volume and mean length, from gastrointestinal and fecal

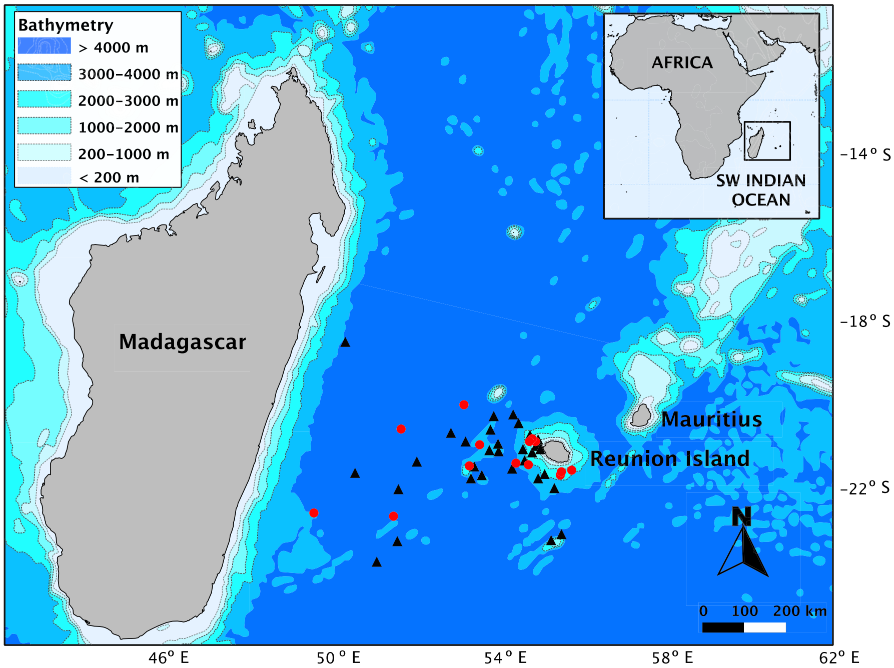

Fig. 1. Locations of 46 by-catch loggerhead sea turtles and bathymetry in the South-West Indian Ocean. Red circles and black triangles represent loggerheads that were found respectively with and without anthropogenic debris. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

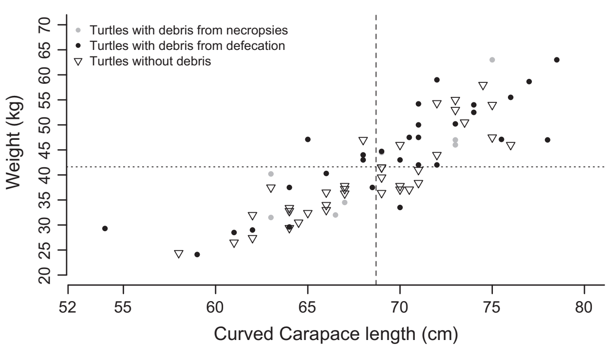

Fig. 2. Curved Carapace Length (CCL) versus body weight from 74 by-catch loggerhead sea turtles in the South-West Indian Ocean. Dashed and dotted lines, respectively, represent the mean CCL and weight of loggerheads. Circles represent loggerheads that ingested debris collected from necropsies (grey) and from defecation (black); triangles denote other loggerheads without anthropogenic debris collected.

samples using the Student's t-test, $\alpha = 0.05$. In addition, we tested difference between the group that ingested debris and the one in which no debris was found using a Student t-test. Finally, we explored possible correlations using Spearman rank correlation coefficients between both the size and the weight and the number, the weight, the volume and the mean length of debris found in feces and in digestive tracks.

3. Results

The mean size (CCL) ± Standard Deviation (SD) of 74 loggerheads was 68.7 ± 4.99 cm and the mean weight ± SD was 41.61 ± 9.52 kg (Fig. 2). Anthropogenic debris were found in 38 (51.4%) of either gut or feces. Twenty-one did not survive so data were obtained from necropsies and nine had ingested debris. Twenty-nine released marine debris by defecation that was collected floating at the surface of individual basins. However, for six of these, data on debris information were missing. Defecation of debris occurred from 6 to 41 days after the surgery.

From 32 specimens with debris analyzed, we found a total of 1315 pieces of debris, corresponding to a total mass of 524.7 g and a total volume of 819.5 ml (Table 1). Between 1 and 149 pieces of debris were found in the samples (Fig. 3a), with a mean ± s.e of 41.09 ± 7.22 pieces per turtle. For most of the individuals ($n = 27$, 84.4%), the total weight of debris found was lower than 30 g (Fig. 3b). The mean weight of debris collected per animal was 16.4 ± 2.85 g corresponding to a mean volume of 25.61 ± 4.06 ml. The maximum weight of debris collected (75.05 g) was recorded in the feces of one individual that survived (CCL = 71 cm, weight = 50 kg). In the group that did not survive, the maximum weight of debris recorded was 45.56 g (CCL = 67 cm, weight = 34.5 kg). The mean length of debris measured per turtle ranged from 1.3 cm to 9.86 cm (mean ± s.e: 2.96 ± 0.3 cm) (Fig. 3c).

Among the debris categories, we counted 1265 pieces of plastic (96.2%). The mean relative percent of hard plastics per animal was 79.9% ± 3.69% and appeared in every turtle that ingested debris (Table 2). The occurrence of other plastic types was also important with plastic caps and soft plastics (composed essentially by plastic bags) accounting for 53.1% and 71.9% respectively. The fishing related items (composed essentially by ropes) occurred in 31.3% of turtles with debris, but these debris represented rather a small proportion of debris collected per turtle (2.93% ± 1.37%). Although natural marine debris such as wood, seabird feathers, substratum and shells, represented one percent of total debris ingested, it appeared in 21.9% of the turtles. Other miscellaneous debris (i.e. rubber, tissue/paper and tar) were present in no more than two turtles.

In considering the plastic category alone, as it represented 96.2% of the total debris ingested, hard white and clear plastics accounted together for more than half of the plastic content (Fig. 4). In average, hard colored and blue plastics represented respectively 12.5% ± 2.59% and 9.61% ± 2.66% of plastics ingested per turtle.

Although we found higher amount of anthropogenic debris in the gastrointestinal samples than in the feces, no significant

Table 1
Number, weight, volume and mean length of debris by $n = 32$ by-catch loggerhead sea turtles obtained from necropsies and defecation.

	Range of number (mean ± s.e)	Range of weight (g) (mean ± s.e)	Range of volume (mL) (mean ± s.e)	Range of mean length (cm) (mean ± s.e)
All turtles ($n = 32$)	1–149 (41.09 ± 7.22)	0.18–75.05 (16.4 ± 2.85)	0.26–106.8 (25.6 ± 4.06)	1.3–9.86 (2.96 ± 0.3)
Necropsies ($n = 9$)	6–141 (45.2 ± 14.4)	4.27–45.56 (18.8 ± 4.71)	5.52–60.79 (29.7 ± 6.46)	1.73–7.6 (3.5 ± 0.57)
Defecation ($n = 23$)	1–149 (39.5 ± 8.5)	0.18–75.05 (15.4 ± 3.56)	0.258–106.8 (24 ± 5.1)	1.3–9.86 (2.7 ± 0.35)

Table 2
Quantification and frequency of occurrence *F* of debris types ingested by $n = 32$ by-catch loggerhead sea turtles. n_i represents the number of loggerheads that ingested the type of debris *i*.

Category	Type *i*	Total number	% of total	Mean percent per turtle ± s.e	n_i	*F* (%)
Plastic	Hard plastic	1108	84.26	79.88 ± 3.69	32	100
	Soft plastic	120	9.13	11.29 ± 2.65	23	71.9
	Plastic caps	37	2.81	2.94 ± 0.79	17	53.1
Fishing items	Line	3	0.23	0.57 ± 0.45	3	9.4
	Rope	20	1.52	2.93 ± 1.37	10	31.3
	Polystyrene	5	0.38	0.67 ± 0.54	2	6.3
	Fishing stopper	1	0.08	0.08 ± 0.08	1	3.1
Miscellaneous	Rubber	2	0.15	0.26 ± 0.23	2	6.3
	Tissue/paper	2	0.15	0.13 ± 0.53	2	6.3
	Tar	4	0.30	0.29 ± 0.26	2	6.3
	Natural debris	13	0.99	0.94 ± 0.37	7	21.9

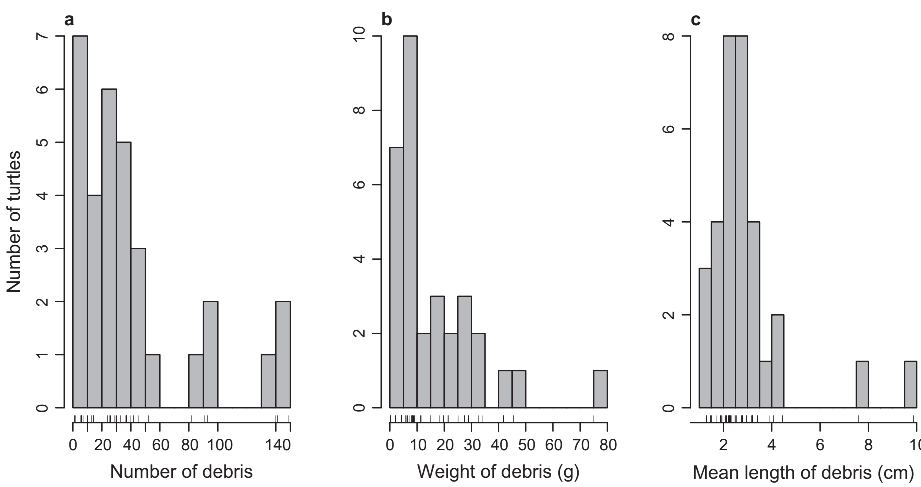

Fig. 3. (a) Number, (b) weight and (c) mean length of anthropogenic debris collected in 32 by-catch loggerhead sea turtles.

differences were found between samples obtained from defecation and those from necropsies in terms of number ($t = -0.505$, $df = 30$, $p = 0.617$), weight ($t = -0.859$, $df = 29$, $p = 0.397$), and volume of debris ($t = -0.604$, $df = 28$, $p = 0.551$), However, despite our uneven samples between gut content and fecal samples we found a higher mean length of debris collected in dead specimens ($t = -2.615$, $df = 29$, $p = 0.014$).

The mean size and weight of turtles that released debris (collected in gut and feces) were not significantly different from those that did not release debris (respectively, $t = 0.746$, $df = 72$, $p = 0.458$ and $t = 1.766$, $df = 72$, $p = 0.082$). There was also no significant correlation between the size of the turtles and the number ($r_s = 0.069$, $p = 0.708$), the weight ($r_s = 0.172$, $p = 0.346$), the volume ($r_s = 0.121$, $p = 0.509$), and the mean length ($r_s = 0.060$, $p = 0.742$) of the debris collected. Likewise, no significant correlations were detected between turtle's body weight and the number ($r_s = 0.064$, $p = 0.727$), the weight ($r_s = 0.179$, $p = 0.324$), the volume ($r_s = 0.204$, $p = 0.262$), and the mean length ($r_s = 0.335$, $p = 0.062$) of debris collected.

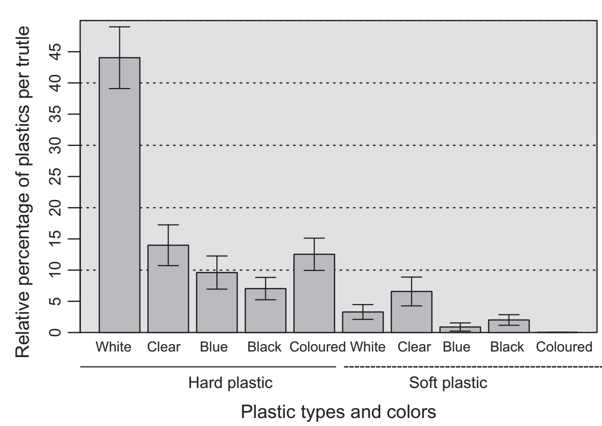

Fig. 4. Combined plastic types and colors collected in the 32 by-catch loggerhead sea turtles. Reported as an average of the percentage of each plastic type and color. Error bars indicate ± standard errors.

4. Discussion

In the present study we report a significant frequency of occurrence of anthropogenic debris found in the digestive tract and feces of loggerheads by-caught in the South-West Indian Ocean. More than half of the specimens (51.4%) had ingested marine debris. This highlights the magnitude of the pollution of anthropogenic debris in the South Indian Ocean. Similar results of occurrence in loggerheads were found in the South-western Pacific (57.1%; Boyle and Limpus, 2008), in the Gulf of Mexico (47%; 51.2%; Plotkin and Amos, 1988; Plotkin et al., 1993) and in the Central Mediterranean Sea (48.1%; Casale et al., 2008). The highest occurrence of anthropogenic debris recorded in loggerheads is in Mediterranean Sea, in the Western Mediterranean: 79.6% (Tomás et al., 2002) and in the Tyrrhenian Sea: 71% (Campani et al., 2013). However, the amount of anthropogenic debris in terms of number, weight and volume per loggerhead from the South-West Indian Ocean is higher than in the other regions previously mentioned. Plastics accounted for 96.2% of all collected items. This is consistent with other studies that reported the ubiquity of plastics in loggerheads (e.g. Tomás et al., 2002; Casale et al., 2008; Lazar and Gračan, 2011; Campani et al., 2013). Besides, Schuyler et al. (2013) recently showed that plastic was the most widely reported debris item ingested by all sea turtles in analyzing 37 studies published on debris ingestion by sea turtles. The prevalence of plastics in oceanic loggerheads from the South-West Indian Ocean could reflect a predominance of this kind of marine debris floating in these oceanic waters.

Some authors have suggested a low oceanic feeding discrimination strategy to explain the prevalence of plastics in their digestive tracks (Tomás et al., 2002; Lazar and Gračan, 2011); while others have proposed that sea turtles demonstrate a trend towards selectivity in ingesting by mistake anthropogenic products that resemble their natural preys (Gramentz, 1988; Plotkin et al., 1993). Schuyler et al. (2012) argued that in green turtles *Chelonia mydas*, there is ingestion selectivity for fragmented balloons that resemble jellyfish or squids. Campani et al. (2013) also suggested that loggerheads are more attracted to sheet plastic because of its resemblance to jellyfish. Likewise, plastic bags may be also confounded with gelatinous preys also called the "plastic jellyfish" as it has been reported on leatherback turtles *Dermochelys coriacea* (Mrosovsky, 1981). Similarly, we found high occurrence of plastics especially of singular shape like plastic caps (present in 53.1% of our *C. caretta* that ingested plastics). Plastic caps are similar in shape to organisms like Cirripedia *Lepas spp*, *Janthina spp*. (Gastropoda) or the pneumatophore of the Chondrophore *Velella velella* (Hydrodia). These species are neustonic organisms found globally floating at and near the surface and are the common prey found in the diet of oceanic loggerheads in the central North Pacific (Parker et al., 2005). Therefore on the basis of these considerations, our results partially support the hypothesis that more plastic items are ingested by loggerheads because of their resemblance of natural preys in oceanic waters and their opportunistic habit of feeding on items floating at or near the surface. The hypothesis that loggerheads have a low feeding discrimination also received support from this study as we collected heterogeneous types of materials in terms of shape and colors some of which debris was not similar to any prey species.

Out of 21 necropsied sea turtles, we recorded nine that ingested anthropogenic debris. The primary cause of their death may be here attributed to esophagus, stomach lesions or perforation by a fishing hook preceding potential bacterial infection rather than to debris ingestion. However, two dead loggerheads had ingested significant masses of marine debris (>30 g), which could have weakened the turtles and impeded their recovery. The ingestions of debris by loggerheads that did not survive rehabilitation were compared with those that successfully recovered. The number, weight, volume and the mean length of debris were higher in loggerheads that died. These results were not statistically significant except for the mean length of debris. However, this result cannot be fully confirmed because plastics cannot be seen by radiology on live sea turtles. Furthermore, debris collected in fecal samples were more likely to be eroded and fragmented into smaller pieces in passing through the entire digestive track than those found in gut samples. These results partially support the underestimation of anthropogenic debris ingestion obtained from feces as Schuyler et al. (2013) recently underlined. On the other hand, necropsies restrict the analysis to deceased sea turtles. Although we did not observe evident obstructions during necropsies, long persistent solid debris are more likely to obstruct the digestive track or cause ulcerations and intestinal injuries, which can weaken the physiological condition of the turtle impeding their ability to survive as by-catch fisheries. The death of sea turtles due to debris ingestion generally occurs when the digestive tract is obstructed (e.g. Bjorndal et al., 1994; Bugoni et al., 2001; Lazar and Gračan, 2011). Our data illustrate the capacity of loggerheads to eliminate large quantities of anthropogenic debris and to survive on these ingestions. When the hook removal was successful most of the by-catch loggerheads were able to defecate marine debris. For instance, the turtle that released the highest number (149 items) and weight of debris (75.05 g) recorded in our study survived and was successfully released back into the wild. The tolerance of loggerhead to debris ingestion is supported by previous studies that reported low mortality as a direct consequence of plastic ingestions (e.g. Plotkin and Amos, 1988; Bjorndal et al., 1994; Tomás et al., 2002; Tourinho et al., 2010). Out of a sample of 454 dead turtles that were found to have ingested debris, 9% were assumed to have been killed directly by the ingestion of plastics (Schuyler et al., 2013).

The ingestion of plastics and other anthropogenic debris is likely to have sub-lethal side effects, increasing the possibility of an individual's death (Hutchinson and Simmonds, 1991). The debris ingested by the 29 loggerheads that survived in this study has the potential of producing sub-lethal effects. The sub-lethal effects of anthropogenic debris on sea turtles such as dietary dilution (McCauley and Bjorndal, 1999), disruption in energy metabolism with declining blood glucose concentrations (Lutz, 1990) or the absorption of toxins (Bjorndal, 1997) are presumably more common than lethal effects (National Research Council, 1990) but are also difficult to measure. Furthermore, we observed lesions on the carapace of rehabilitated loggerheads that ingested debris. These symptoms could be attributed to effects of their diet on the carapace growth, in which different contaminants constituents of plastics could weaken the carapace development. These lesions disappeared after the turtles were appropriately fed and given treatments with antibiotics. More research is needed to identify and assess these sub-lethal effects on sea turtles and the consequences on sea turtle populations. Oehlmann et al. (2009) demonstrated that plasticizers (e.g. Phthalates and Bisphenol A), components of plastics and other man-products, can disrupt the functioning of hormonal systems in various groups of marine organisms and affect their development and reproduction. According to Bjorndal (1997), debris ingestion could have long-term demographic consequences on sea turtle populations through declining growth rates, fecundity and late sexual maturation, which may precipitate a population at a greater risk of vulnerability.

The biometric variables (i.e. size CCL and weight) of all by-catch loggerhead sea turtles did not demonstrate any differences in debris collection, as the mean size and weight of the sample

loggerheads were not significantly different between individuals that released debris and those that did not. In addition, we did not find any correlation between the biometric variables and the amount of ingested debris in terms of number, weight, volume and mean length. These results suggest that all loggerheads in this study may be equally susceptible to ingesting anthropogenic debris. This absence of correlation between the size of sea turtles and the amount of ingested debris was also found in previous studies (Bugoni et al., 2001; Tomás et al., 2002; Lazar and Gračan, 2011; Schuyler et al., 2012), as well as between body weight of sea turtles and the ingestion of debris (Tourinho et al., 2010). In contrast, Campani et al. (2013) found highly significant correlations between: CCL and plastic weight, sea turtle weight and plastic weight. Some studies showed a trend toward a decrease of debris ingestion with age, in particular older coastal benthic-feeding turtles appear less likely to ingest debris than young oceanic turtles (Balazs, 1985; Plotkin and Amos, 1990). Schuyler et al. (2012) demonstrated that this trend is also true when the probability of ingestion is considered. The authors used a wide range of body size from post-hatchling to adult individuals that included both adult benthic and juvenile oceanic turtles.

Seventy-one out of seventy-four (95.9%) by-catch loggerheads in our study belong to a class size of CCL > 60 cm (Fig. 1), which it is the approximate size at which loggerhead sea turtle starts recruiting to neritic habitats along the South African coastlines (Hughes, 1974b) and switching their feeding behavior from pelagic to benthic preys (Hughes, 1974a). However, they start recruiting to neritic habitats at larger sizes in other regions, for instance in Queensland, Australia, at a minimum size of CCL > 70 cm (Limpus et al., 1994). Furthermore, the life history model in juvenile loggerheads considering this ontogenic habitat shift from the oceanic environments to neritic coastal waters is much more complex than it was assumed as this shift does not necessarily occur or may be even reversible (McClellan and Read, 2007; Mansfield et al., 2009; McClellan et al., 2010). Therefore, despite the large sizes of loggerheads in our study (mean ± SD: 68.7 ± 4.99 cm), the area where they have been accidentally captured is far off the continental shelves and their stomach and feces contents confirm the oceanic stage of these turtles. We believe that all sampled individuals were in their juvenile oceanic stage and foraging on pelagic prey. The majority of late juveniles foraging in oceanic South Western Indian ocean waters are presumably moving to their natal site to northern rockery of Oman, while others to the South African nesting sites (Dalleau et al., in press). The authors argue that the loggerhead sea turtles emerging from the northern rookeries, converge on Reunion Island and East Madagascar waters follow a trans-equatorial developmental cycle. This behavior associated with a complex life cycle makes loggerheads prone to ingesting marine debris (Witzell and Teas, 1994; Lutcavage et al., 1997). Juvenile sea turtles with low oceanic feeding discrimination are more at risk from debris ingestion than adult benthic-feeding turtles (Balazs, 1985; Casale et al., 2008; Schuyler et al., 2012; Schuyler et al., 2013). Thus, when transported by currents in the water column or floating at the surface, marine debris could be easily confused with natural prey.

Research is needed to establish the extent of impacts of anthropogenic debris on marine life and the long-term consequences on the ocean's ecosystems. The high frequency of occurrence and the significant presence of anthropogenic debris found in loggerheads from the South-West Indian Ocean highlight the gravity of this pollution that could impact negatively their long-term demography. It appears likely that this pollution constitutes a major threat to sea turtles on a global scale and therefore must be mitigated rapidly through a global improvement of waste management. Effective measures are required to prevent the disposal of plastics into the oceans through reduction, re-use and recycling. In addition, appropriate local legislation associated with educational programs for schools and professional users of the seas are necessary to promote changes in plastic disposal practices. Such programs must be conducted in order to emphasize the ecological responsibility of Humankind towards the oceans that provide valuable resources on which so much humanity depends.

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