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Research article

Investigation on beach debris on the historical nesting grounds of green turtles (*Chelonia mydas*) in Hainan Island, South China

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ABSTRACT

Hainan Island used to be the most important nesting ground of green turtles in China before they disappeared about 37 years ago. Habitat degradation is one of the main reasons for the disappearance of sea turtles. Therefore, it is necessary to take action to evaluate and recover the historical nesting grounds if we hope for sea turtles to return in the future. In this study, we surveyed the beach debris on 13 historical nesting grounds of green sea turtles on Hainan Island. The beach debris on these nesting grounds mainly consisted of plastic, cigarette butts, foam, glass, and nylon, with plastic (including plastic blocks, cigarette butts, and foam) being the dominant type, accounting for 78.92% in number, followed by glass. The average density of beach debris was 0.314 pieces·m^{-2}. Compared to other nesting grounds, the average quantity and density of beach debris in Hainan was lower, but the proportion of plastic debris was extremely high. After categorizing debris type, we found that most was from human coastal activities (35.54%), with debris at tourist beaches having the biggest proportion of debris from smoking supplies. The distribution characteristics of beach debris were related to the function of the beach, density of tourist, and the intensity of beach debris cleaning. It is recommended to further strengthen the emission reduction and clean-up of beach debris in Hainan Island, so as to restore the nesting habitat of sea turtles as soon as possible.

1. Introduction

According to the definition of the United Nations Environment Programme (UNEP), marine debris refers to "persistent, man-made or processed solid waste in the marine and coastal environment" [1]. Debris that enters the marine environment can be transported long distances by ocean currents and then deposited on the coastline or the seabed [2]. Marine debris has been identified as a source of habitat degradation that threatens marine species [3]. Sea turtles are often injured, stranded, and dead due to eating marine debris by mistake or being entangled by them [3,4]. Marine debris not only affects the survival of sea turtles in the ocean, but also affects the nesting and hatching process of sea turtles on shore [5]. Beach debris on the nesting grounds interferes with the nesting activities and

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nest site selection of female sea turtles, causing nesting failure or change the nest distribution pattern [6–9], as well as hinder newly hatched hatchlings from crawling to the sea, increasing the chance of being predated [10–12]. In addition, the presence of marine debris can change the incubation temperature in nests, thereby changing the sex ratio and population structure of sea turtles [13].

In recent years, the research on the impact of beach debris on sea turtles is increasing, mainly focusing on the types and distribution of beach debris at nesting grounds [14,15], the impact of beach debris on sea turtles' nesting and hatching [6,10], source analysis and speculation of debris [16], and suggestions on beach debris treatment [17]. Therefore, marine debris has become an important indicator for habitat quality assessment of sea turtle nesting grounds [10]. In China, there are few studies on debris pollution for marine animals, with only Zhang et al. (2020) investigating the beach debris in the green turtles nesting ground on Paracel (Xisha) Islands of South China Sea [18].

Historically, nesting grounds of green sea turtle are scattered across Hainan Island [19,20]. However, sea turtles almost disappeared from all nesting grounds due to illegal hunting, beach encroachment and marine pollution, and the last record of nesting activity was 37 years ago [21–23]. Some successful cases have shown that if the historical nesting grounds are strictly managed and protected, it is possible for sea turtles to return and lay eggs. For example, a former "landfill" was turned into a beach where turtles can safely nest through a large-scale beach cleaning at Versova Beach in Mumbai, India, and local residents witnessed the return of nesting sea turtles after a 20-year absence [24]. The Chinese government is attaching more importance to sea turtle conservation and encouraging the restoration of historical habitats for sea turtles. Therefore, it is necessary to locate and evaluate historical nesting grounds before they are selected as potential restoration sites. In this study, we surveyed the beach debris on 13 historical nesting grounds of green sea turtles in Hainan to reveal 1) the quantity and composition of beach debris, 2) the distribution characteristics of beach debris, and 3) the sources and origins of beach debris. Management suggestions are also put forward according to these survey results.

2. Materials and methods

2.1. Study area

Hainan Island is located in the northwestern part of South China Sea. The island is dominated by agriculture and tourism, with a total of 50 million visitors from China and abroad each year, and most of its beaches have been built into tourist attractions. There were many historical nesting grounds of green sea turtles around Hainan Island and 13 sites were selected in this study, including Da'aowan, Fengjiawan, Longwan'gang, Shimeiwan, Li'an'gang, Qingshuiwan, Tufuwan, Dadonghai, Yazhou Qu, Fushicun, Qiziwan, Lingaojiao

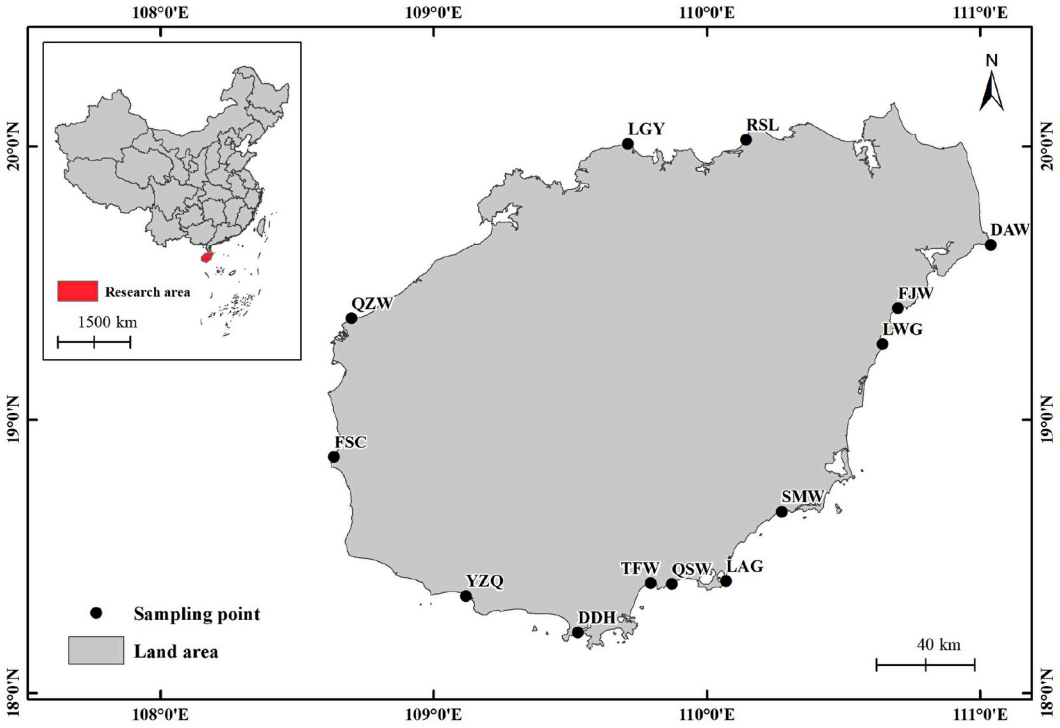

Fig. 1. Map of Hainan island and 13 historical nesting grounds of green sea turtle, sampling sites including Da'aowan (DAW), Fengjiawan (FJW), Longwan'gang (LWG), Shimeiwan (SMW), Li'an'gang (LAG), Qingshuiwan (QSW), Tufuwan (TFW), Dadonghai (DDH), Yazhou Qu (YZQ), Fushicun (FSC), Qiziwan (QZW), Lingaojiao Fishermen Village (LGY), and Rongshanliao (RSL). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Fishermen Village, and Rongshanliao (Fig. 1).

2.2. Survey methods

Each investigated beach is taken as a sampling point, and three quadrats were randomly selected from each sampling point (The interval between quadrats is ≥ 100 m). Each quadrat was vertically divided into four transects (50 m × 1 m). The first transect is the high tide line and the fourth is the vegetation line. The second and third transects are set between the high tide line and the vegetation line (The distance between transects is 4–14 m, which is divided by the beach width). The visible debris (>2.5 cm) on the beach surface of each transect was collected, classified and counted [2,10,25]. The calculation method of debris fragment density (D, piece·m^{-2}) is as follows:

$$D = n/S$$

where n is the total number of debris fragments (pieces) and S is the area of the survey sample (m^2) [26].

As the beach function is the main determinant of the source of beach debris [27], according to the method of the Northwest Pacific Action Plan & UNEP Regional Seas Programme (2007), we divided the beaches into six categories based on beach function: G1 (Village beach), G2 (Fishing port beach), G3 (Tourist beach), G4 [Economic development zone beach (real estate, industrial and other coastal development activities)], G5 (Unused beach), G6 (Urban beach) [28].

Based on the type of material, the beach debris was divided into 12 categories such as plastic blocks, foam, metal, rubber, and fabric (cloth). The source of beach debris was classified as human coastal activities, shipping/fishing activities, smoking supplies, medical/hygiene supplies, and other debris [29,30].

2.3. Statistical analysis

Excel and SPSS 19.0 software were used for statistical analyses. All data were tested for normality and homogeneity of variance before statistical analysis. The single factor variance method was used to analyze the difference of debris density at each beach. The relevant data are expressed as mean ± standard deviation (Mean ± SD), and $P < 0.05$ is considered significant (two-tailed test).

3. Results

3.1. Composition and quantity of beach debris

In this study, a total of 2448 pieces of beach debris were collected from 13 nesting grounds. The average number of beach debris was 0.31 m^{-2}, of which plastic (consist of plastic blocks, cigarette butts items, and foam) were the most abundant material encountered, with 1932 pieces making up 78.92% of all the debris found, followed by glass (Table 1). This result was consist with other similar surveys around the world, reporting plastic as the most abundant debris in coastal areas [14,18,31–35].

The average density of beach debris in Hainan Island was low compared with four other nesting grounds of sea turtles, even the Paracel (Xisha) Islands of South China Sea. But the proportion of plastic was quite high, similar to other grounds (Table 2).

3.2. Distribution characteristics of beach debris

Beach debris density on the 13 historical nesting grounds varied according to their functional types and the intensity of debris cleaning. The unused beach (G5) had no one to clean up the beach debris all year round, and the average density of beach debris was the highest (0.523 piece m^{-2}), while the average density of debris in fishing port beach (G2) was the lowest (0.175 piece m^{-2}). Regular removal of beach debris is an effective strategy to decrease beach debris, as the density of beach debris at beaches with daily clean up

Table 1
Total composition and the amount of debris on the historical nesting grounds of green turtles on Hainan island.

Debris composition type	*N*	Proportion (%)	Average density (pieces·m^{-2})
Plastic block	1477	60.33	0.19
Cigarette butts	274	11.19	0.04
Foam	181	7.39	0.02
Glass	106	4.33	0.01
Nylon	103	4.21	0.01
Rubber	78	3.19	0.01
Paper products	70	2.86	0.01
Fishing lines/nets	52	2.12	0.01
Metals	48	1.96	0.01
Wooden categories	25	1.02	0.00
Fabric (cloth) class	24	0.98	0.00
Others	10	0.41	0.00
Total	2448	100.00	0.31

Table 2
Comparison of different debris types in sea turtle nesting sites in different parts of the world.

Sea turtle nesting grounds	Debris quantity density (piece·m^{-2})	Density of plastics (piece·m^{-2})	Percentage of plastic debris (%)
Hainan Island, China	0.314	0.25	78.92
Sea Turtle Conservation Area in NE Brazil [16]	2.9	2.14	74
Jekyll Island, Georgia, USA [15]	–	–	85
Northeastern Levantine coasts of Turkey [36]	25.11	19.5	77.65
Qilianyu Islands, Northeastern Xisha Islands, China [18]	0.379	0.31	82.04

–: Not mentioned in the literature.

(FSC, LAG, adn RSL), was much lower than the beaches of the same function type that had no cleaning. However, the density of beach debris were still higher on some tourist beaches (G3) even with daily clean up, such as DDW and FJW (Table 3).

3.3. Sources of beach debris

The beach debris on the 13 nesting grounds were primarily from human coastal activities (35.54%), followed by shipping or fishing activities (14.01%), and smoking supplies (12.46%) (Table 4). Comparing the sources of debris between different types of beach functions, we found that beach debris on tourist beaches (G3) had the biggest proportion of smoking supplies, and the smallest proportion of shipping/fishing activities. Beach debris from sources of shipping or fishing activities were concentrated in village beach (G1) and fishing harbour beach (G2) (Fig. 2).

4. Discussion

The average density of beach debris on historical nesting grounds of sea turtles in Hainan island is relatively low compared with other nesting grounds in the world, even smaller than that in Paracel (Xisha) Islands of South China Sea, which is the largest extent nesting grounds of green turtles in China [18]. But the proportion of plastic beach debris is quite high, which should be directly related to the sharp increase of marine plastic debris in recent years. From 1950 to 2017, global plastic products increased from 1.5 million tons to 355 million tons [37], and the quantity and pollution degree of plastic debris in the ocean increased continuously [38–40].

Regular removal of beach debris is an effective strategy to decrease the debris and improve habitat quality [17]. The different density of beach debris among the 13 nesting grounds is related to the beach functional type and the intensity of beach cleaning. Three historical nesting grounds showed almost no debris on beach due to daily clean up. However, Dadonghai (DDH), which is a famous tourism area, had the highest density of beach debris despite daily cleaning. Large amounts of household debris, such as cigarette butts and straws, were still found at DDH after each clean-up. At present, beach debris management around the world still pays more attention to large-size debris than small-size debris, so many small plastic products such as bottle caps, straws, and cigarette butts will be left on the beach [41,42]. These small debris items are dangerous because they are likely to be ingested by marine animals such as turtles and seabirds, which will bring serious health and life threats to them [16,43,44]. Therefore, we suggest that local management departments should strengthen the cleaning work of beach debris, especially small debris, and increase the intensity and frequency of debris cleaning in these historical sea turtle nesting grounds. Meanwhile, the normalization of beach debris cleaning should be one of the focuses of beach management and future habitat restoration.

The beach debris on Hainan Island is primarily from coastal zone development activities on the land, the production and living of residents in coastal areas, shipping or fishing activities, and the debris by tourists. Beach debris on tourist beaches had the biggest proportion of smoking supplies, followed by fishing harbour beach. Beach debris from sources of shipping or fishing activities were concentrated in village beach (G1) and fishing port beach (G2). It was reported that debris, such as plastic, fishing nets, and cigarette

Table 3
Beach debris density on 13 historical nesting grounds of green sea turtles on Hainan Island.

Beach function type	Beach debris density (piece·m^{-2})	Survey sample	Beach debris density (piece·m^{-2})	Debris cleaning
G5 Unused beaches	0.523	DAW	0.523	No cleaning
G1 Village beach	0.418	LGY	0.523	No cleaning
		LWG	0.442	No cleaning
		FSC	0.29	Clean-up daily
G4 Economic Development zone beach	0.399	QZW	0.408	No cleaning
		TFW	0.39	Clean-up daily
G3 Tourist beach	0.245	DDH	0.543	Clean-up daily
		FJW	0.308	Clean-up daily
		SMW	0.127	Clean-up daily
		QSW	0	Clean-up daily
G2 Fishing harbour beach	0.175	YZQ	0.525	No cleaning
		LAG	0	Clean-up daily
		RSL	0	Clean-up daily

Table 4
Classification statistics of debris sources.

Sources of debris	Category	Number of debris (pieces)	Proportion (%)
Other debris	Tires, Fluorescent tubes, Window screens, Wires, Light bulbs, Glass, etc.	921	37.62
Human coastal activity	Plastic bottles, Fast food boxes, Beverage cans, Plastic bags, etc.	870	35.54
Shipping or fishing activities	Discarded fishing nets and debris, Fishing lines, Floats, etc.	343	14.01
Smoking supplies	Cigarette butts, Cigarette packs, Lighters, etc.	305	12.46
Medical or hygiene products	Syringes, Discarded medicine bottles, Sanitary napkins, Diapers, etc.	9	0.37

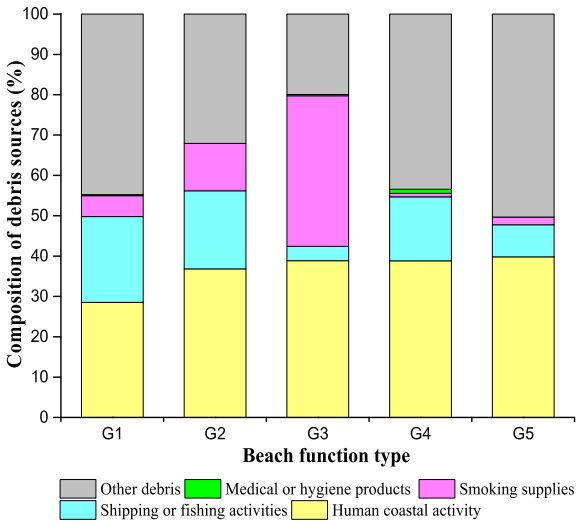

Fig. 2. Classification and statistics of different debris sources between the different beach function types on Hainan Island.

butts, were usually discarded by people randomly at tourism areas and fisherman wharves [45]. Therefore, effective measures should be taken to reduce beach debris when restoring these historical nesting grounds. It is necessary to make strict laws or regulations to reduce random discarding of debris on beach. The sorting and recycling of nets and rafts used in fishing activities should be encouraged. The promotion of alternatives to traditional fishing gear, such as the replacement of the currently commonly used polystyrene foam floats with sturdy polystyrene floats, should be accelerated. In addition, we suggest that the public awareness of environmental protection should be enhanced through public education activities focusing on marine environmental protection, reducing plastic usage, and discarding debris on beach [16,46]. Finally, it is also necessary to provide an effective and timely restoration system for the polluted nesting grounds to reestablish suitable habitats for sea turtles.

Author contributions statement

Ting Zhang: Conceptualization; formal analysis; investigation; methodology; writing-original draft; writing-review & editing. Liu Lin: Conceptualization; funding acquisition; formal analysis; investigation; methodology; writing-original draft; writing-review & editing. Meimei Li: Investigation, methodology, writing-review & editing. Li Kong: Investigation, methodology. Jichao Wang: Validation; visualization; writing-review & editing. Hai-Tao Shi: Conceptualization; funding acquisition; writing-review & editing.

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Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of interest's statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to

influence the work reported in this paper.

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