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Possible link between derelict fishing gear and sea turtle strandings in coastal areas

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ABSTRACT

Ghost fishing via a derelict fishing gear (DFG) is a critical threat to marine organisms. To explore the effect of DFG on sea turtle strandings, the DFG distribution was compared at two sites on Jeju Island (South Korea) with a contrasting number of strandings. Coastal areas in northern Jeju Island were surveyed during dives with scuba equipment, and the DFG from two sites, Gwideok-ri and Sinchang-ri was collected and compared in terms of quantity and size of the items. Fishing line was more common, longer, and thicker in Gwideok-ri than in Sinchang-ri, while other types of DFG did not differ between the two sites. In addition, necropsies on two loggerhead sea turtles discovered on Jeju Island found fishing lines with fishing hooks in the oral cavity of both carcasses. This suggests that derelict recreational fishing lines may pose a significant threat to sea turtles in coastal areas.

1. Introduction

Derelict fishing gear (DFG), which is abandoned, lost, or otherwise discarded fishing gear, is of growing concern in marine ecosystems due to its various negative impacts which have increased with the more widespread use of plastic material for this gear (Macfayden et al., 2009). In South Korea, it is estimated that about 11,436 tons of traps and 38,535 tons of gillnets are discarded annually (Kim et al., 2014). DFG can continue to entangle commercially important fish species, endangered species, and benthic life over many decades, leading to the maiming, amputation, increased drag, restricted movement, or choking of marine animals such as sea turtles (Lewison and Crowder, 2007), cetaceans (Jacobsen et al., 2010), pinnipeds (Karamanlidis et al., 2008), and marine birds (Bugoni et al., 2008).

Sea turtles are one of the most endangered marine reptiles in the world. According to the International Union for Conservation of Nature (IUCN), six out of seven sea turtle species are critically endangered, vulnerable, or endangered, and flatback sea turtle (*Natator depressus*) is data deficient (IUCN, 2021). Sea turtles are associated with various habitats, migratory behaviors, and complex life histories and are thus highly vulnerable to the impact of DFG (Nelms et al., 2016). Both nesting females and hatchlings may become entangled in DFG on nesting beaches preventing them from nesting or making it into the sea respectively (Ramos et al., 2012). Because sea turtles spend their first three to five years floating with oceanic currents, they are likely to encounter marine debris that follows the same currents. Floating DFG behaves in a similar manner to a floating algal mat, acting as an ideal substrate for hydrozoa, bryozoan, and barnacles (Stelfox et al., 2020). Sea turtles, which are attracted to floating algal mats in search of shelter and food, will thus interact with floating DFG (Carr, 1987).

In South Korea, five species of sea turtles have been observed: the green (*Chelonia mydas*), loggerhead (*Caretta caretta*), leatherback (*Dermochelys coriacea*), hawksbill (*Eretmochelys imbricata*), and olive ridley turtle (*Lepidochelys olivacea*), with *C. mydas* and *C. caretta* accounting for half of the reported sightings (Kim et al., 2019; Moon et al., 2009), most of which have been around Jeju Island (Jung et al., 2012b). In Jungmun, the southern part of Jeju Island, a hatchling crawling into the ocean was reported, so it is presumed to be used as a sporadic nesting place (Jung et al., 2012a). Many of the *C. mydas* rescued from set nets have been observed moving toward Japan or China, or remaining around Jeju

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Island (Jang et al., 2018). The habitat and nesting sites for sea turtles in the Northern Hemisphere are expected to move northward due to climate change (Reece et al., 2013). Therefore, it is important to monitor sea turtles in Jeju Island, which is likely to be the northern limit for sea turtles in East Asia, to reduce the negative impacts of human activity, such as being included in commercial bycatches.

In this study, we investigated submerged marine debris to assess the impact of land-derived marine debris and DFG from local commercial fishing activity on the strandings and mortality of sea turtles on Jeju Island. We compared the debris between two coastal sites that differ in their number of strandings and conducted necropsies to determine which types of marine debris are most likely to negatively affect the sea turtles on Jeju Island.

2. Materials and methods

2.1. Study areas

The study sites were Gwideok-ri (GD: 33.44398 N, 126.27992 E; Fig. 1a) and Sinchang-ri (SC: 33.34842 N, 126.17759 E; Fig. 1b) on the northwestern coast of Jeju Island in South Korea, where many interactions between sea turtles and humans have occurred (Moon et al., 2009). Although the two sites are only approximately 15 km apart, they were selected because the number of non-targeted interactions differs greatly between the two. According to unpublished data, 25 cases of sea turtle bycatches and strandings have been reported at GD, whereas only six cases have been reported at SC from 2008 to 2019 (Fig. 1c). Both areas have shallow water depths with high biodiversity with low waves which are relatively suitable for sea turtles to rest and feed. Also, they use set nets for fisheries and have small ports for fishing boats.

2.2. Investigation

To investigate submerged DFG nearshore, an underwater investigation was conducted (Al-Najjar and Al-Shiyab, 2011) following the diving research protocol from Reef Check California (Shuman et al., 2011) from August 19, 2020, to September 5, 2020. Two researchers entered the water with SCUBA gear (Hollis BCD L.T.S., Huish Outdoors, Utah, USA). At each site, 19 quadrats (5 m × 25 m) were placed with two anchors and a tapeline. To record the exact location, a GPS device (GPSMAP-64S, Garmin International Inc., Kansas, USA) was fixed to a buoy floating on the surface held by one of the divers. All of the marine debris on the sea floor was recorded using a camera (Tough TG-5, Olympus Inc., Tokyo, Japan) and collected into a mesh bag. Large marine debris that cannot fit into a mesh bag was lifted to the coast using a buoy.

2.3. Sample treatment

The collected marine debris was dried and sorted into the following categories: fishing line, lure, fishing net, weight, rope, non-fishing-gear related plastic, metal, fiber, glass, hook, buoy, rubber, and others. Knotted fishing lines and ropes were untied and their length measured using a tape measure and their diameter measured using Vernier calipers (CD-15PSX, Mitutoyo Corp., Kawasaki, Japan). The fishing nets were

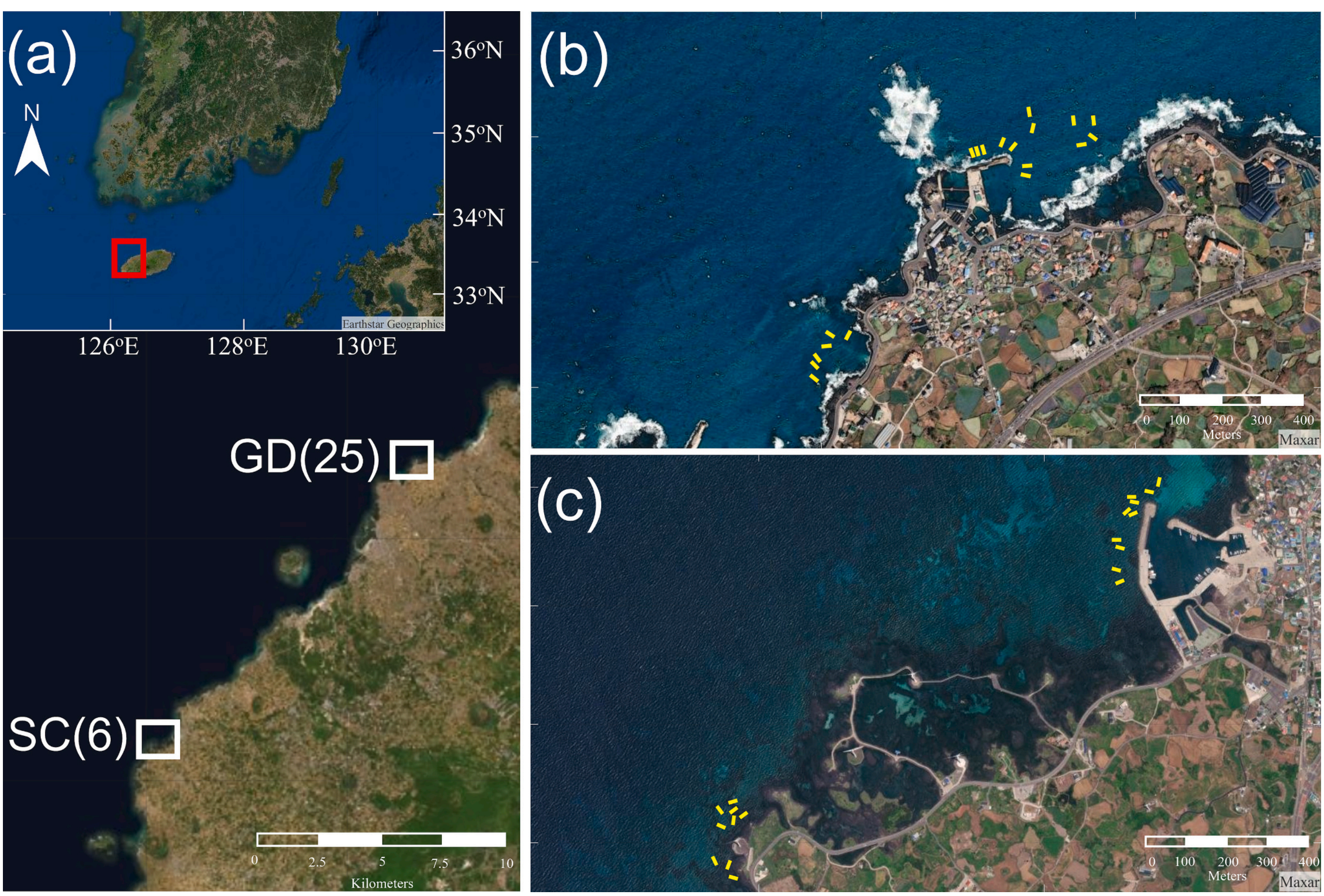

Fig. 1. Research sites of Jeju Island. The diving investigation was carried out at (a) the northwestern coast of Jeju Island. In (b) Gwideok-ri (GD), 25 stranded sea turtles were found from 2008 to 2019. In (c) Sinchang-ri (SC), six sea turtles were stranded over the same period. At each site, 19 quadrats, indicated by the yellow boxes, were placed where scuba diving was conducted to collect derelict fishing gears. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

also untied, and then the surface area and diameter were measured. To measure the surface area of the nets, the size of the mesh and the number of mesh openings were multiplied. The source of the DFG was assumed whether it originated from recreational fishing or commercial fishing according to the characteristics like diameter, general use, or shape.

2.4. Necropsy

Two loggerheads (JJ200821–1; Fig. 5a and JJ200821–2; Fig. 5b) were found at Panpo-ri (33.36604 N, 126.19935 E) on June 6, 2019, and at Sagye-ri (33.22632 N, 126.30335 E) on November 26, 2019. Neither carcass exhibited external injuries except for fishing lines connected to the oral cavity. The carcasses were transported to the Korea Fisheries Resources Agency immediately following discovery. They were cleaned with tap water and kept frozen in a polypropylene bag at $-40\ ^{o}$ C. The necropsies were performed according to the Manual for Necropsy of Sea Turtles (Work, 2000). The body size of the thawed carcasses was measured. Incisions were made on the side of the ventral carapace to determine the condition of the body fat and muscles, the scapula was removed, and the connective tissue was incised to expose the internal organs. The digestive organs were then removed, and the sphincter was closed with cable ties to prevent the mixing of the contents. The removed organs were separated into individual stainless trays. External damage was observed, and the internal tissue was sampled after incisions with cleansed utensils. For JJ200821–1, the esophageal tissue that the fishing hook had penetrated was excised and placed in a 10 % formalin solution. For JJ200821–2, the fishing hook that pierced the beak was removed and its size was measured using Vernier calipers.

2.5. Statistical analysis

Because the measurements were non-normally distributed (Shapiro−Wilk test; $p < 0.05$ for all measurements), Mann-Whitney U test was used to compare the number of fishing lines, nets, lures, and ropes, the length of fishing lines and ropes, and the size of the nets between the two sites. All statistical analyses were run by SPSS software (version 19.0; SPSS, Inc., Chicago, USA), and all data were presented as the mean ± standard error (SE).

3. Results

3.1. Plastic found at the study sites

A total of 403 items were found in an area of 4750 m^2 from 38 quadrats, with an average of 10.61 ± 1.67 items in each quadrate. The collected items included fishing lines, fishing lures, plastic, ropes, weights, fishing nets, metal, fiber, glass, hooks, buoy fragments, rubber, and others, such as clothing fragments and ceramic ware. The fishing lines, lures, ropes, nets, weights, hooks, and buoys were considered DFG (n = 288), accounting for 71.46 % of all items (Fig. 2). Of the DFGs found, fishing lines and fishing lures were more common than ropes and nets (64.24 % and 21.18 %, respectively; Chi-square test; $\chi^2 = 128.771$, $p < 0.001$). In particular, fishing lines and fishing lures, which are mostly used in rock fishing, were the most dominant forms of DFG (45.91 %; Fig. 3).

3.2. Difference in DFG between the study sites

A total of 267 items from GD (14.05 ± 2.89 items) and 136 items from SC (7.16 ± 1.31 items) were collected. There was no significant difference in non-DFG marine debris between GD and SC (5.21 ± 1.53 and 2.47 ± 0.67, respectively; Mann-Whitney U test; $U = 140.5$, $n_1 = n_2 = 19$, $p = 0.236$). In terms of total DFG, an average of 10.47 ± 2.44 items per quadrat were found at GD, compared with 4.68 ± 1.03 items at SC, though this difference was not statistically significant ($U = 130.5$, $n_1 = n_2 = 19$, $p = 0.143$; Fig. 4a). Significantly more fishing lines were found at GD than at SC (5.37 ± 1.19 and 1.53 ± 0.57, respectively; $U = 101.5$, $n_1 = n_2 = 19$, $p = 0.017$; Fig. 4b). The number of fishing lures did not significantly differ between GD and SC (2.58 ± 1.25 and 0.26 ± 0.17, respectively; $U = 147.5$, $n_1 = n_2 = 19$, $p = 0.196$; Fig. 4c), but a large number of lures were found at GD with a large deviation (Fig. 3a). There was no statistically significant difference between GD and SC in the number of nets, ropes, hooks, weights, or buoys (Fig. 4d-h).

The length of the fishing line was significantly longer at GD than at SC (303.06 ± 81.22 cm and 122.79 ± 31.09 cm, respectively; $U = 219.500$, $n_1 = 102$, $n_2 = 29$, $p = 0.005$; Fig. 4i). In addition, the diameter of the fishing lines at GD were significantly thicker than at SC (0.77 ± 0.12 mm and 0.49 ± 0.09 mm, respectively; $U = 205.000$, $n_1 = 102$, $n_2 = 29$, $p = 0.002$; Fig. 4j). Fishing nets and ropes did not show a significant difference between the two sites for their surface area, length, or diameter (fishing net surface area: $U = 52.000$, $n_1 = 11$, $n_2 = 12$, $p =$

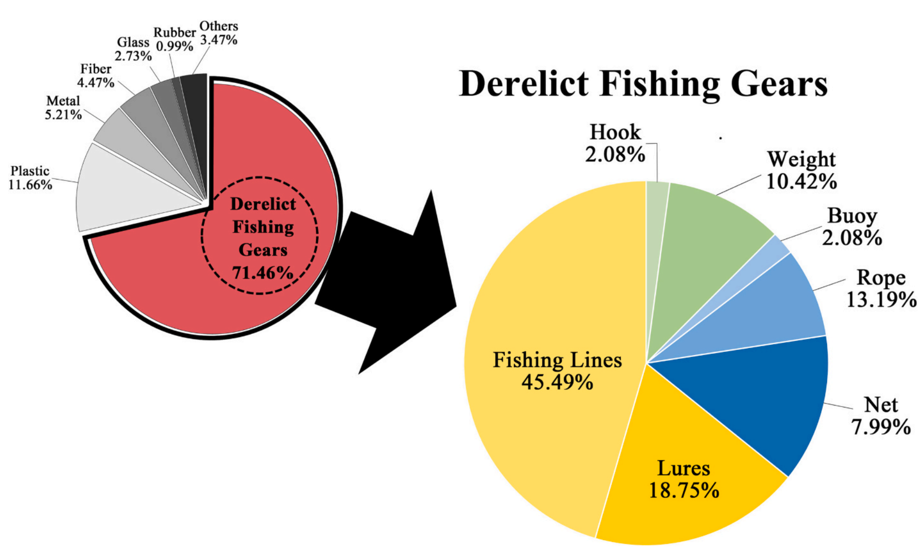

Fig. 2. Marine debris found during the dive expeditions. Each item was counted as a single item regardless of its size. Items shaded in blue are from commercial fishing and those shaded in yellow tones are from recreational fishing. Hooks and weights, shaded in green, are uncategorized due to uncertainty regarding their source. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

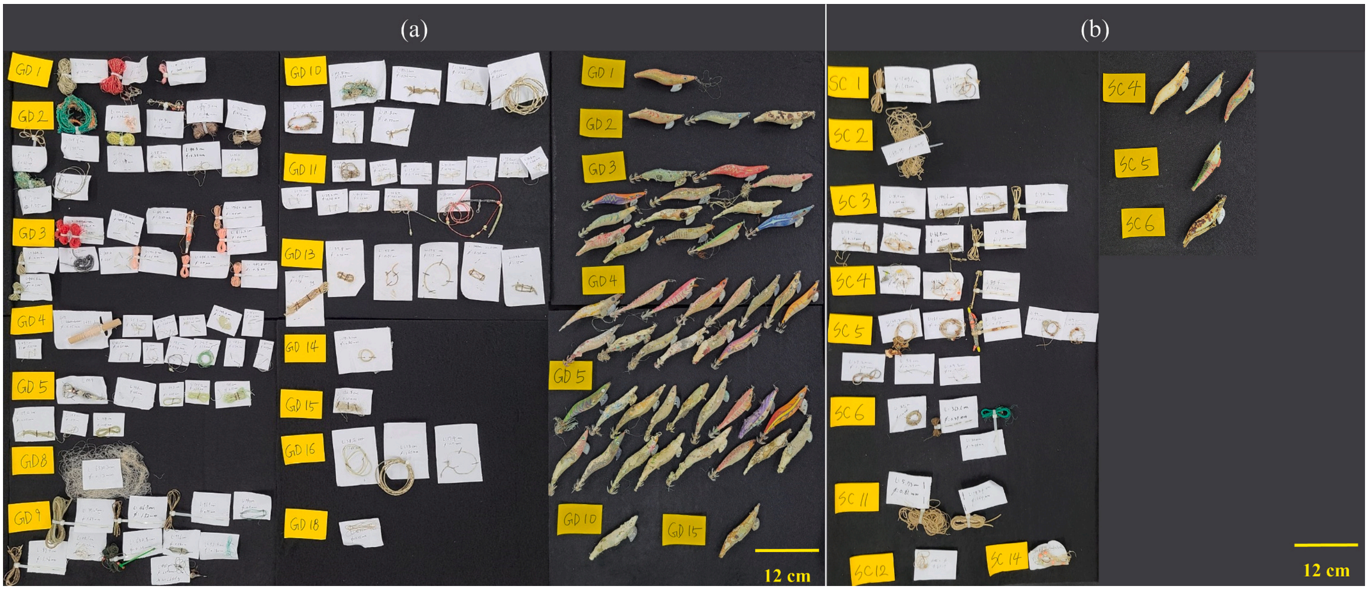

Fig. 3. Fishing lines and fishing lures found at (a) Gwideok-ri (GD) and (b) Sinchang-ri (SC). More fishing lines and lures were found at GD where more sea turtle strandings occurred. The average diameter of the derelict fishing line was 0.77 ± 0.12 mm at GD and 0.49 ± 0.09 mm at SC respectively, which was indicative of the thin fishing lines often used in recreational fishing. The fishing lures were shrimp-shaped, mostly targeting bigfin reef squids (*Sepioteuthis lessoniana*).

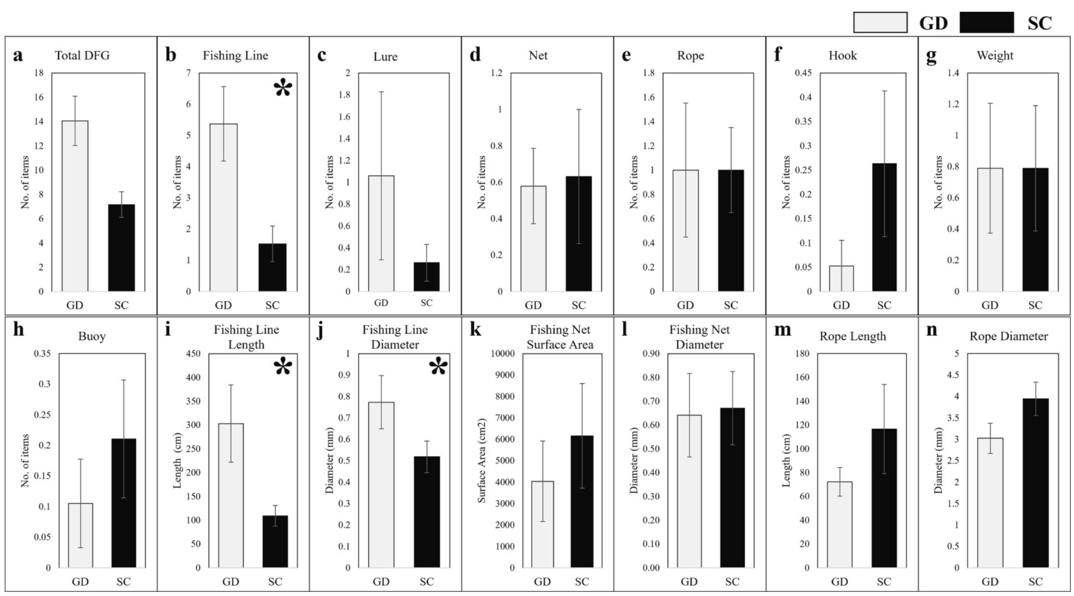

Fig. 4. Comparison of derelict recreational fishing gears (DFG) items found at GD and SC: number of (a) total DFGs, (b) fishing lines, (c) lures, (d) nets, (e) ropes, (f) hooks, (g) weights, and (h) buoys. The (i) length and (j) diameter of the fishing lines, (k) surface area and (l) diameter of the nets, and (m) length and (n) diameter of the ropes were compared. The asterisk (*) indicates a significant difference ($p < 0.05$).

0.389, Fig. 4k; fishing net diameter: $U = 46.000$, $n_1 = 11$, $n_2 = 12$, $p = 0.215$, Fig. 4l; rope length: $U = 152.000$, $n_1 = 19$, $n_2 = 16$, $p = 0.405$, Fig. 4m; rope diameter: $U = 137.000$, $n_1 = 19$, $n_2 = 16$, $p = 0.204$, Fig. 4n).

3.3. Necropsy results

A necropsied loggerhead had a curved carapace length of 91.2 cm (Fig. 5a), and the overall body fat and muscle were well-developed. The fishing line (199.3 cm; Fig. 5c) was hanging out of its oral cavity, connecting through the esophageal hiatus to a fishing hook (width of 2.5 cm and length of 5.0 cm; Fig. 5d) which was embedded in the esophagus 8 cm behind the throat.

The other loggerhead had a curved carapace length of 82.8 cm and was deficient in overall body fat and muscle (Fig. 5b). Two fishing hooks were found: one embedded in the mouth (2.7 × 5.0 cm; Fig. 5e) and the other in the entry to the esophagus (1.5 × 3.5 cm). The wound in the esophagus due to the hook had recovered from previous inflammation, and the hook was abraded (Fig. 5f).

4. Discussion

DFG accounted for 71.46 % of the marine debris found at the study site, indicating that it is the main pollutant in the area. This ratio is in agreement with a previous report of marine debris in the Korean seabed in 2018; trawling for seabed marine debris found that, nets and ropes

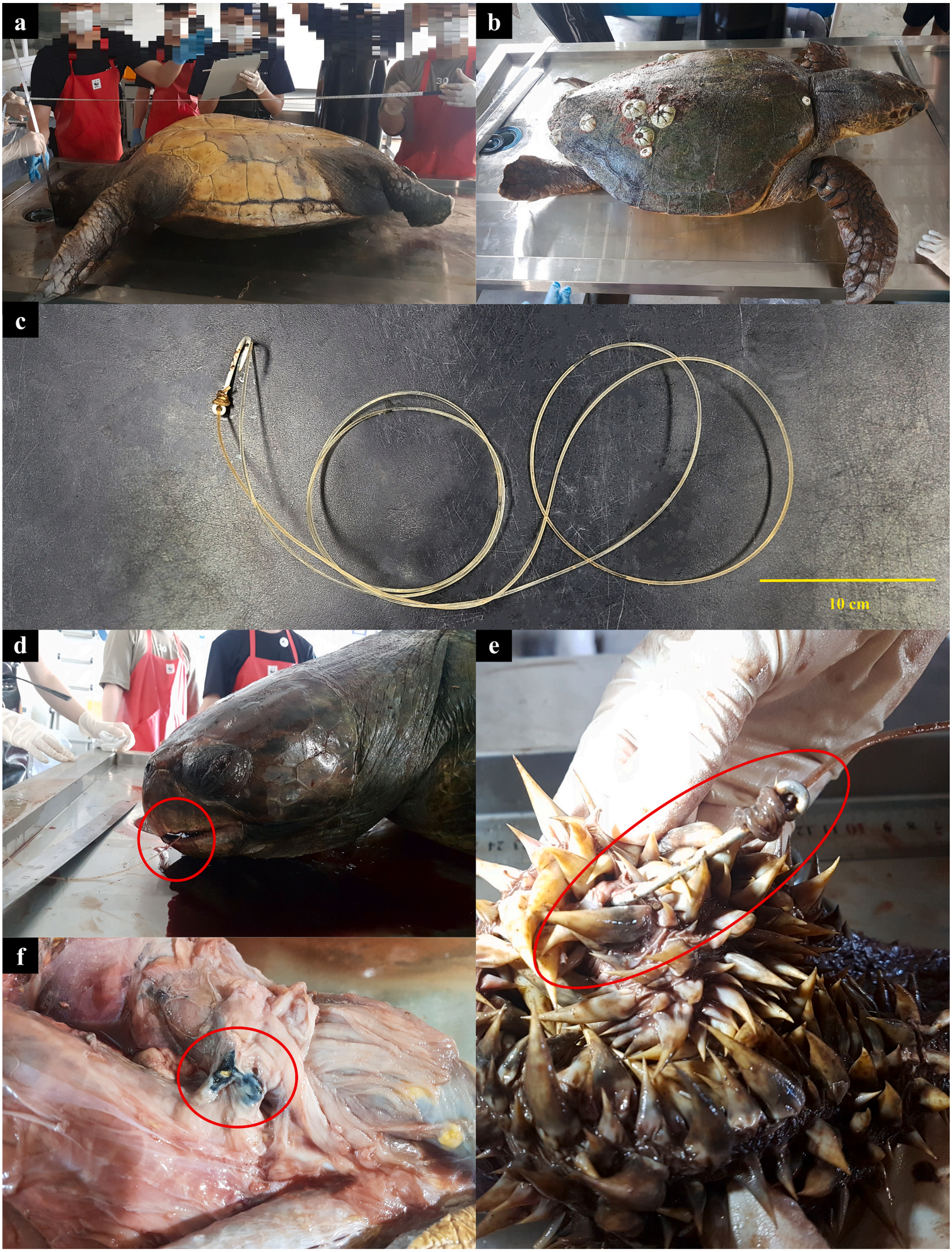

Fig. 5. Necropsies of two stranded loggerhead sea turtles found on Jeju Island: (a) JJ200821–1 and (b) JJ200821–2. Traces of fishing lines were found in both carcasses. (c) JJ200821–1 had a trail of fishing line connected to the (d) oral cavity, and the fishing line trail was connected to (e) a fishing hook piercing the esophagus tissue. (f) JJ200821–2 had inflammation in the esophagus tissue caused by an embedded fishing hook which may have restricted ingestion. The red circles indicate areas affected by fishing hooks. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

were the dominant forms of marine debris (Song et al., 2021). Major plastic debris ingested by a fin whale (*Balaenoptera physalus*) found near Jeju Island were also DFG such as fishing lines, nets, and ropes (Im et al., 2020). However, in the present study, the most common type of DFG was derelict fishing lines followed by ropes and lures, even though fisheries by set nets that produced fishing nets and ropes, were performed in nearby villages. This differs from marine debris found by the trawls or fin whale necropsy. Thus, the dynamics of DFG on the coastal seabed appear to be affected not only by nearby fisheries but also by other influences.

We expected more DFGs to be found at GD where more sea turtles have been stranded or found in bycatch. According to the study by Wilcox et al. (2015), the number of sea turtle strandings is generally correlated with the amount and size of derelict fishing nets washing up on shore. Therefore, the volume of derelict fishing nets was expected to differ between the study sites. However, only fishing-line-related items were significantly different (Fig. 4b,i,j). In particular, more derelict fishing lines that were longer and thicker were found at GD, where more sea turtle interactions have been reported. This indicates that sea turtle stranding is more likely to be affected by the influence of derelict fishing lines than by other forms of DFG.

Sea turtles have a higher risk of interacting with longer and thicker derelict fishing lines, thus increasing the likelihood of serious health problems (Staffieri et al., 2019). If a sea turtle is caught on a fishing line, it can lead to feeding restrictions, respiratory issues, or behavioral failure. If it is entangled with a limb over a long period, the turtle can suffer necrosis or even amputation (Barreiros and Raykov, 2014; Lysiak et al., 2018). Sea turtles can also accidentally ingest DFG while feeding on prey (Pham et al., 2014), which can perforate the digestive system, cause dietary dilution, and damage internal tissues via chemical leaching from the plastic (McCauley and Bjorndal, 1999; Wallace, 1985).

The concern about whether sea turtles would be affected by the fishing lines was supported by the sea turtle necropsies. Both loggerhead carcasses contained scars from fishing lines and hooks. The cause of death for JJ200821–1 appeared to be a result of a bycatch. In particular, given that it had sufficient body fat and muscle and did not have external injuries, drowning caused by fishing line entanglement was likely to be the cause of death. In contrast, judging from its deficient body fat and muscle, JJ200821–2 appears to have died due to the inability to consume food following the ingestion of the fishing line. The fishing hook swallowed by the sea turtle appeared to inflame the digestive tract, severely restricting its ability to feed. Because the number of sea turtles that have undergone necropsy is limited, it cannot be concluded that all sea turtle strandings on Jeju Island are caused by fishing lines. However, the fact that traces of fishing lines were observed in the sea turtle carcasses suggests that the sea turtles in the area are under real threat from this form of DFG (Moon et al., 2022).

Although the deaths of the two turtles in the present study were likely to be caused by commercial fishing based on the size of the hooks and fishing lines, most of the fishing line found at our study sites was <1 mm in diameter (0.71 mm $\pm$ 0.10), while shrimp-shaped lures were commonly found (Fig. 3). In Jeju Island, commercial fisheries are majorly conducted in forms of longline fishing, set net, and gillnets. These commercial fisheries majorly use fishing nets, buoys, ropes, and thick longlines but do not use thin fishing lines or shrimp-shaped lures. Therefore, it is suggested that these forms of DFG originate from non-commercial fishing. We suggest that these forms of DFG may originate from recreational fishing performed in coastal rocks and breakwaters, which are most common on Jeju Island. In summer, recreational fishers aiming for bigfin reef squids (*Sepioteuthis lessoniana*), coming to the shore for spawning from April to May, use thin fishing lines and shrimp-shaped lures (Kang et al., 2009; Tokai and Ueta, 1999). Given the result that the length, thickness, and quantity of the derelict fishing lines found in GD, where more sea turtle strandings occurred, was greater, it is suggested that recreational fishing could have a negative impact on sea turtles foraging along the coast of Jeju Island (Jang et al., 2018).

Unlike commercial fishing which has categories, licenses, and limitations by laws, recreational fishing has no legal enforcement except in some restricted areas. While in the absence of legal regulation, recreational fishing influences various direct and indirect negative effects on the marine environment that decrease the overall quality (Pinnegar et al., 2000). For example, fishing gears used in coastal rocks and breakwaters which are conducted mostly on Jeju Island could be caught and snapped easily by rocks. In case of that, fishing gears can remain in the water and continues to threaten marine animals (Cooke and Cowx, 2004, 2006). In addition, the DFG produced by recreational fishing such as hooks and line can be direct dangers to local wildlife ranging from sessile invertebrates to large animals such as water birds and turtles (Asoh et al., 2004; Chiappone et al., 2005). Non-biodegradable lead sinkers can also accumulate in the environment, which can lead to highly toxic lead poisoning (Garcia-Fernandez et al., 1995). However, despite these negative impacts of recreational fishing, it receives less attention in terms of government regulations and thus its harmful influence can be expected to continue. To reduce the influence and achieve sea turtle conservation, academic research and government regulation are needed. Also, the education and awareness that can inform citizens and tourists about the impact that fishing can have on the endangered sea turtles and the surrounding marine environment must be accompanied.

Unlike fishing lines, there was no significant difference in the other forms of DFG between GD and SC (Fig. 4a). This does not mean that these do not affect sea turtles because the negative effects of fishing nets, hooks, and lures on sea turtles have been reported (Duncan et al., 2017; Stelfox et al., 2019; Vegter et al., 2014; Wilcox et al., 2015). There might be several reasons why there was no significant difference between GD and SC other than the amount of derelict fishing lines. For example, regular underwater clean-ups of DFG are conducted in the area by the city government, which means large quantities of DFG may already have been removed from the sites before our investigation began. To confirm the general distribution of DFG at these sites, further long-term and seasonal research in these coastal waters are required, while systematic data collection and management and more necropsies to determine the causes of death for stranded turtles should be implemented.

5. Conclusion

DFG accounts for the largest proportion of marine debris in the coastal waters of Jeju Island. Therefore, there is a possibility that sea turtles in this area may be affected by DFG. More and thicker derelict fishing lines were found at the site with more sea turtle interactions, which raises the possibility that fishing line influences sea turtle strandings. In addition, the abundance of DFG generated by recreational fishing suggests that this form of DFG may be a significant threat to the sea turtles along the coast of Jeju Island.

CRediT authorship contribution statement

Kyungsik Jo: Conceptualization, Visualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft. **Jibin Im:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – review & editing. **Byeong-yong Park:** Investigation, Writing – review & editing. **Boongho Cho:** Investigation, Writing – review & editing. **Soobin Joo:** Investigation, Writing – review & editing. **Byung-Yeob Kim:** Investigation. **Taewon Kim:** Conceptualization, Project administration, Supervision, Funding acquisition, Writing - review & editing.

Declaration of competing interest

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.

Data availability

Data will be made available on request.

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