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Spatial patterns of marine litter on the Arabian Gulf's major offshore sea turtle nesting islands

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Abstract
Marine litter poses growing risks to the Arabian Gulf's major turtle nesting islands, yet its composition and fine-scale distribution have never been quantified. We combined two complementary surveys on Jana and Karan Islands—the region's largest hawksbill (*Eretmochelys imbricata*) and green turtle (*Chelonia mydas*) rookeries. First, 988.3 m^2 of 0.75 m × 0.75 m photo-quadrats (June 2017) recorded litter cover and item counts across 587 grid nodes; second, 4050 m^2 of 5 m × 5 m ground quadrats (October 2020) measured marine litter count and mass across beach, vegetation-line and vegetation-within zones at 18 shoreline stations. Photo quadrats showed that plastics, styrofoam, and wood dominated stranded items. A total of 32 litter groups were observed with highest contribution by debris count from plastic drinking bottles (63.6% at Jana; 42.9% at Karan) and by litter mass from processed wood (69.5% at Jana; 68.8% at Karan). Fishing-related litter comprised 8.5% by mass and 10.4% by count at Jana Island, and 16.2% by mass and 11% by count at Karan Island. Jana Island had a higher number of plastic bottles than Karan Island. Vegetation-line plots retained roughly twice the debris density and mass of both open-beach and interior plots ($p < 0.001$). These patterns indicate that macroplastic accumulation already overlaps with core nesting habitat at the external fringe of the vegetation line and is likely to generate additional pressures such as microplastic deposition in nests and ingestion by adults and hatchlings. Continued monitoring, together with seasonal clean-ups and studies on interacting stressors, would guide adaptive management of the Gulf's primary turtle rookeries.

1 Introduction

Marine litter is defined as any persistent, manufactured, or processed solid material discarded, disposed, or abandoned in the marine environment, including those that wash up on beaches or sink to the seafloor [1–3]. Marine litter has become ubiquitous in most seas and beaches around the world, occurring both in densely populated and remote areas [1]. For plastics alone, it is estimated that 4.8 to 12.7 million tonnes of waste enter the oceans from land sources globally, with projections of cumulative inputs reaching as high as 250 million tonnes by 2025 [4].

In the Regional Organization for the Protection of the Marine Environment (ROPME) Sea Region, where the Arabian Gulf (hereafter referred to as Gulf) is located, marine litter distribution remains poorly documented and is often described

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only in grey literature. Previous work on the United Arab Emirates (UAE) coastline found much higher litter loads on Gulf shores than along the Gulf of Oman, with plastic fragments, fishing floats and netting making up most of the debris [6]. However, there are no peer-reviewed, island-scale litter survey published for Saudi waters [5]. Recent surveys show that plastics dominate Gulf shorelines, typically accounting for more than 60% of items [5, 7]. Litter inputs are expected to stay high because the Gulf countries are among the world's top 10% in bottled-water consumption per capita and also have high usage rates of single-use plastic bags [5, 8].

Beyond shoreline aesthetics, marine litter now carries clear ecological costs. Field studies show that plastic obstacles delay sea turtle nesting and hinder hatchling egress [13], while field monitoring reveals that extreme sand temperatures already lower hatch success on Gulf islands [14]. Litter ingestion has been documented in 86% of stranded green turtles (*Chelonia mydas*) along the eastern UAE coast [9], 29% of olive ridleys (*Lepidochelys olivacea*) and 83% of hawksbills (*Eretmochelys imbricata*) in Gulf of Oman and UAE waters [10], and 74% of green turtles and 43% of loggerheads (*Caretta caretta*) on Omani beaches [11]. Although strandings in the Saudi Arabian Gulf are often attributed to intensive fishing and shrimp-trawling activity, no necropsy-based assessments have been undertaken, so litter ingestion levels in stranded turtles remain unknown [12]. Together, these findings suggest that accumulating debris may compound existing thermal and physical stresses on regional turtle rookeries. A portion of litter originating from coastal cities eventually accumulates in other remote areas including offshore turtle nesting islands, potentially affecting their ecosystems.

The Saudi offshore islands of Jana and Karan host the Gulf's largest nesting populations of hawksbill and green turtles, with ~ 500 and ~ 1000 nesting females per year, respectively [17–20]. Geophysical profiling of these islands has linked subsurface geology to active sediment removal [21], while satellite time-series document a progressive narrowing of their shorelines [22]; both aforementioned studies flag ongoing beach loss as a direct threat to the nesting habitat and long-term persistence of the islands' sea-turtle populations. Systematic litter data are required to evaluate how litter may obstruct nesting females, entangle hatchlings, or alter nest micro-climates [13].

In this study, we conducted the first island-wide, in situ marine litter survey on Jana and Karan. Our objectives were to (i) classify and quantify debris by material type, (ii) map its spatial distribution relative to shoreline features, and (iii) provide baseline data for assessing potential impacts on sea-turtle nesting and hatchling emergence.

2 Materials and methods

2.1 A. Study system

The two largest islands in the Saudi Arabian waters of the northern Arabian Gulf—Jana (27° 22′ 06.85″ N, 49° 53′ 50.85″ E) and Karan (27° 43′ 05.05″ N, 49° 49′ 28.91″ E)—lie ~ 46 km and 80 km offshore of mainland and are about 40 km from each other. Although similar in most aspects, Karan (2 024 m × 632 m; perimeter 5.3 km) is roughly twice the size of Jana (1 105 m × 300 m; perimeter 2.6 km) [15]. Both islands are low and flat, supported by twin spines of beach-rock; storm berms on their north-west flanks accumulate flotsam and jetsam. Vegetation is sparse and dominated by halophytic shrubs, although long-term vegetation index analyses revealed gradual greening on windward edges over the past three decades [16].

2.2 B. 2017 survey with a 50 m × 50 m grid on Jana and Karan Islands

In June 2017, we established systematic 50 m × 50 m grids covering the vegetated interiors of Jana and Karan Islands with sampling stations positioned on the nodes or the points where grid lines intersect (Fig. 1). The grids comprised 148 nodes on Jana and 439 on Karan; lower and upper beach zones were excluded to focus on litter that accumulates within the vegetation boundary.

At each grid node, three 75 cm × 75 cm quadrats were tossed at random and photographed with geotagged digital cameras. Material type of litter within each image was classified following Supplementary Table S1 and their areal cover quantified. Counts of individual items were recorded by material category. Percent cover was quantified in ImageJ by delineating regions of interest (ROIs) around debris items [23]; the image-analysis workflow is illustrated in Supplementary Fig. S1. The mean litter cover for a node was the arithmetic average of the three quadrats.

Spatial visualization was performed in QGIS [24]: node-level mean percent covers were interpolated with the Contour plugin to generate isopleth maps of litter distribution.

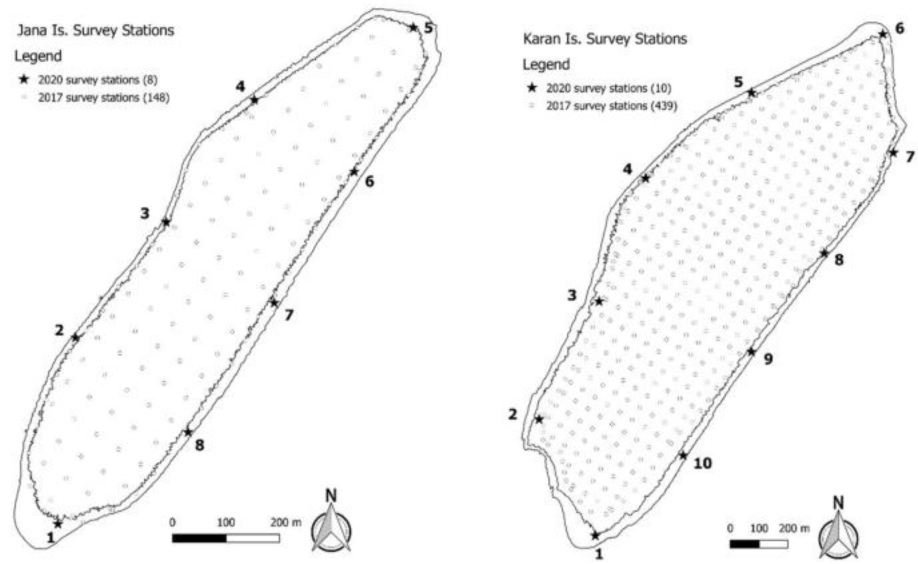

Fig. 1 Map of Jana and Karan Islands, in the Arabian Gulf, showing sampling nodes for the June 2017 (50 m × 50 m) photo-quadrat survey (grey dots) and shoreline stations for the October 2020 (5 m × 5 m) beach-zone survey (numbered start symbols)

2.3 C. 2020 beach zone survey with 5 m × 5 m quadrats

In October 2020, we assessed marine litter across three shoreline zones: Beach (B), Vegetation Line (VL) and Vegetation Within (VW). At each zone, we established three replicate 5 m × 5 m quadrats, spaced 10 m apart to avoid pseudo-replication. The VW quadrat was placed 10 m landward of the VL edge, while the B quadrat lay 2 m seaward of the VL edge (adjusted landward where the beach was exceptionally wide). The spatial arrangement of the quadrats is illustrated in Supplementary Fig. S2.

Eight survey stations on Jana and ten on Karan (Fig. 1) were selected at approximately regular intervals around each island's perimeter (i.e. roughly 450–500 m at Karan Is and 300 m at Jana Is). Within every quadrat, litter was identified, classified, and quantified (Supplementary Table S1) according to the UNEP/IOC Guidelines on Survey and Monitoring of Marine Litter [1]. All litter was then counted and weighed to the nearest 0.01 kg.

2.4 D. Statistical analysis

The spatial homogeneity of total litter counts and mass among the stations around each island was first evaluated with Pearson's χ^2 tests [25]. Pearson's chi-squared tests were performed to test whether the distribution of litter, either by total litter count or mass, were uniformly distributed among the stations.

To examine zone effects on litter accumulation in each island, we performed a nested anova with linear mixed-effects model (LME; nlme package) in R v4.2.2 [26] using the October 2020 survey data (i.e. litter mass, litter count) specifying Zone (B, VL, VW) as a fixed effect and Station as a random effect [27]. LMEs are generally robust to moderate departures from normality and heteroscedasticity [28]. Comparisons of means among the three zones were carried out using Tukey post hoc test in the *glht* function of multicomp R package. The significance of the random effect (Station) from our model was tested by comparing the mixed-effect model to a model without the Station term, which was built using the *gls* function in the *nlme* package. Restricted Maximum Likelihood (REML) was the method used to estimate the variance in the models. The two models were compared using the anova function with the selection of the model providing the lower Akaike's Information Criterion (AIC). This comparison was necessary to statistically determine if the variation between sampling Stations was significant, thereby justifying the inclusion of the random effect to account for non-independence in the data arising from the nested sampling design.

Raw item counts and mass remained non-normal after log transformation, so a Kruskal–Wallis test was used followed by a Nemenyi post-hoc comparisons to test for location-level differences within each zone. All statistics were run in R v4.2.2 [26], and α was set at 0.05.

3 Results

3.1 A. 2017 survey with a 50 m × 50 m grid on Jana and Karan Islands

3.1.1 Percent litter cover

Figure 2 presents contour maps of mean litter cover (%) interpolated from the 50 m × 50 m grid nodes. On Jana, the highest cover values cluster along the western vegetated shoreline—both northern and southern sectors—with the north-western belt extending well into the interior. On Karan, a similar high-cover band occurs on the north-west beach, but interior penetration is limited there and instead greatest in the southern half of the island. In both cases, the western flanks—those facing the Saudi mainland—contained the highest percent cover of litter.

3.1.2 Classification of marine litter

Analysis of the photo-quadrats showed that plastics dominate the litter composition on both islands, accounting for 63.6% of items on Jana and 42.9% on Karan (Table 1). Among plastics, single-use drinking bottles were most abundant—33.6% of all items on Jana and 26.8% on Karan—followed by miscellaneous plastic fragments (11.4% and 20.7%, respectively) and expanded-polystyrene (styrofoam) pieces (20.7% and 22.0%). Non-plastic categories included processed wood, glass shards, rubber, metal cans, and small amounts of fishing gear. Fishing-related litter—principally foam buoy fragments, nylon rope, and net off-cuts—comprised 3.5% of items on Jana and 1.2% on Karan**.** Overall, the litter assemblages were heavily skewed toward buoyant plastic, styrofoam, and lightweight wood products.

3.2 B. 2020 beach zone survey with 5 m × 5 m quadrats

3.2.1 Distribution of litter by mass and item density

The distribution of marine litter along the peripheral boundaries of the islands in the Beach, Vegetation Line, and Vegetation Within zones was not uniform. At the station level, more litter had accumulated on the northwestern side of both islands, which is consistent with the prevailing wind (Fig. 3, Table 2). Pearson's χ^2 tests confirmed that total mass and total item count differed significantly among stations on both islands ($p < 2.2 \times 10^{-16}$; Supplementary Table S2), indicating non-homogeneous litter loads.

On Jana, stations along the western shoreline carried the greatest litter mass and item counts, whereas eastern and northern shores were comparatively light. On Karan, the north-western sector (stations 4 and 5) exhibited the highest loads; other sectors carried markedly less material.

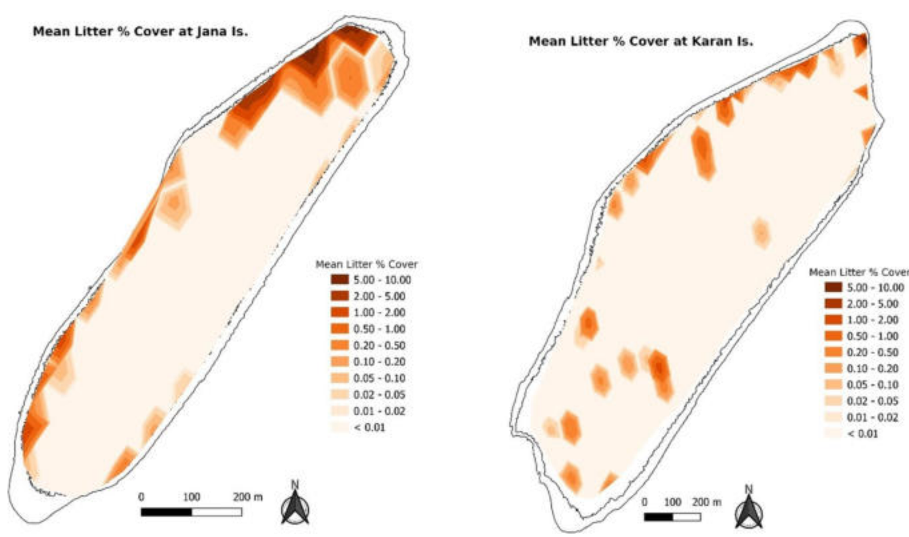

Fig. 2 Contour maps of mean marine litter percent cover recorded on Jana and Karan Islands during the June 2017 photo-quadrat survey

Table 1 Classification and percent contribution (by item count) of marine litter recorded in the photo-quadrat survey in 2017

Litter type	Litter Code	Jana Is (% of Count)	Karan Is (% of Count)
Plastic bottle	PL02	33.6	26.8
Plastic pieces	PL24	11.4	20.7
Styrofoam	FP04	20.7	22
Foam brown	FP03	1.4	0
Wood	WD04	9.3	8.5
Charcoal	WD06	5	0
Glass bottle	GC02	2.1	2.4
Glass fluorescent	GC05	0	1.2
Nylon sack	PL16	0	1.2
Nylon rope	PL19	1.4	1.2
Nylon net	PL20	0.7	0
Rubber	RB08	0.7	0
Metal canister	ME04	0.7	0
Debris unknown		12.9	15.9
Number of stations		148	439
Number of photo-quadrat*		443[a]	1314[b]

*Total number of photo-quadrats taken across all sampling grid nodes per island

[a]No image taken for second replicate photoquadrat at Jana Grid Node 17

[b]Grid Node 80 at Karan Island was positioned over the sea and not on land

Litter codes follow [1], also available in the Supplementary Table S1

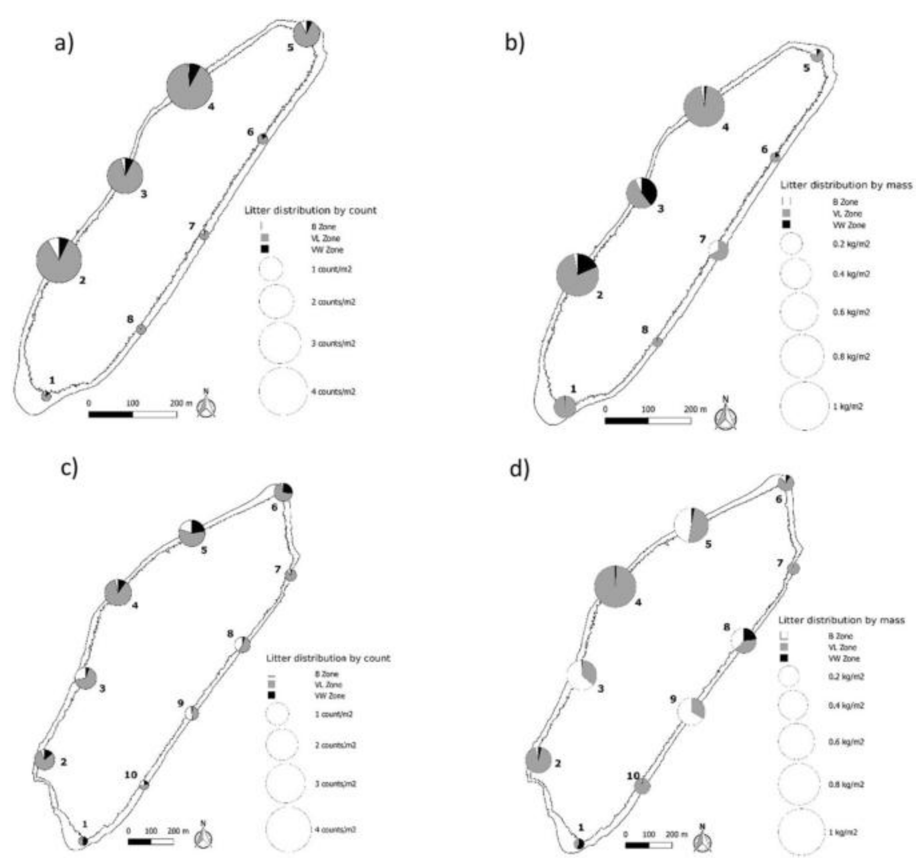

Fig. 3 Spatial distribution of marine litter recorded in October 2020. Panels **a** and **c** show total item counts; panels **b** and **d** show total mass (kg) for the nine 25 m^2 quadrats (225 m^2 total) surveyed at each shoreline station on Jana (top) and Karan (bottom). At every station, a pie chart illustrates the percentage contribution of the three zones (white, gray, black, respectively)—Beach (B), Vegetation Line (VL) and Vegetation Within (VW)—to its total litter. Pie-chart diameter is scaled to litter density

Table 2 Number of litter items and their mass (kg), as totals from the nine 5 m × 5 m quadrats (225 m^2) at each station on Jana and Karan Islands

Island	Station	Total litter count	Total litter mass (kg)	Density by count (count/m^2)	Density by mass (kg/m^2)
Jana	1	26	46.7	0.12	0.21
	2	814	171.6	3.62	0.76
	3	503	88.9	2.24	0.40
	4	838	159.7	3.72	0.71
	5	275	15.3	1.22	0.07
	6	40	1.9	0.18	0.01
	7	31	39.2	0.14	0.17
	8	10	6.3	0.04	0.03
Total		2537	529.6		
Karan	1	30	10.4	0.13	0.05
	2	180	68.9	0.80	0.31
	3	208	92.6	0.92	0.41
	4	320	179.2	1.42	0.80
	5	308	123.9	1.37	0.55
	6	149	26.5	0.66	0.12
	7	58	15.0	0.26	0.07
	8	109	65.1	0.48	0.29
	9	81	78.3	0.36	0.35
	10	35	27.8	0.16	0.12
Total		1478	687.7		

There were consistent zone-level patterns (Fig. 3): at most stations on Jana, the Vegetation Line (VL) zone held the largest share of litter by both count and mass. Conversely, several stations on Karan showed substantial accumulation in both the Beach (B) and VL zones, likely influenced by large processed-wood items that remained stranded on the open beach.

Figure 4 presents box-and-whisker plots summarizing litter loads in the three shoreline zones on Jana and Karan. The nested mixed-effects ANOVA showed that the VL zone contained significantly more debris than either B or VW on both islands (Fig. 5 a and c) (Supplementary Table S3; $p < 0.05$). The random effect of *Station* was retained in all final models except the Karan mass dataset (Fig. 5 d).

3.2.2 Distribution of marine litter by zone

The median item count and mass of marine litter varied among stations within each zone of the two islands (Supplementary Fig. S3 and Supplementary Table S4). At Jana Island, the median litter count and mass differed significantly among Beach-zone stations: stations 6 and 8 recorded lower counts than station 2. In the Vegetation-Line zone, station 4 exceeded station 8 in median item count, whereas in the Vegetation-Within zone station 3 carried greater litter mass than station 8.

In Karan Island, the median litter count and mass varied significantly among stations in the Beach zone and in the Vegetation-Line zone (counts only) and Vegetation-Within zone (counts only). Litter mass did not differ among Karan stations in the Vegetation-Line or Vegetation-Within zones.

3.2.3 Composition of marine litter by material type

Across both islands we recorded 32 distinct litter codes grouped into eight material classes: cloth (CL01), paper/cardboard (PC03), foamed plastic (FP01, FP02, FP03, FP04), general plastic (PL01, PL02, PL03, PL04, PL06, PL07, PL08, PL13, PL16, PL18, PL19, PL20, PL24), glass/ceramic (GC02, GC04, GC05, GC08), metal (ME03, ME04, ME05, ME08, ME10), rubber (RB02, RB08), and wood (WD04, WD06) (Supplementary Table S1). Plastic dominated the inventory, accounting for 17 of the 32 codes recorded, including items such as foam sponge, buoy fragments, insulation and packaging foam, single-use bottles, food containers, rope and fishing nets. Glass and ceramic litter—mainly beverage bottles, light bulbs and fluorescent tubes—were also present, as were metal items such as aluminum drink cans

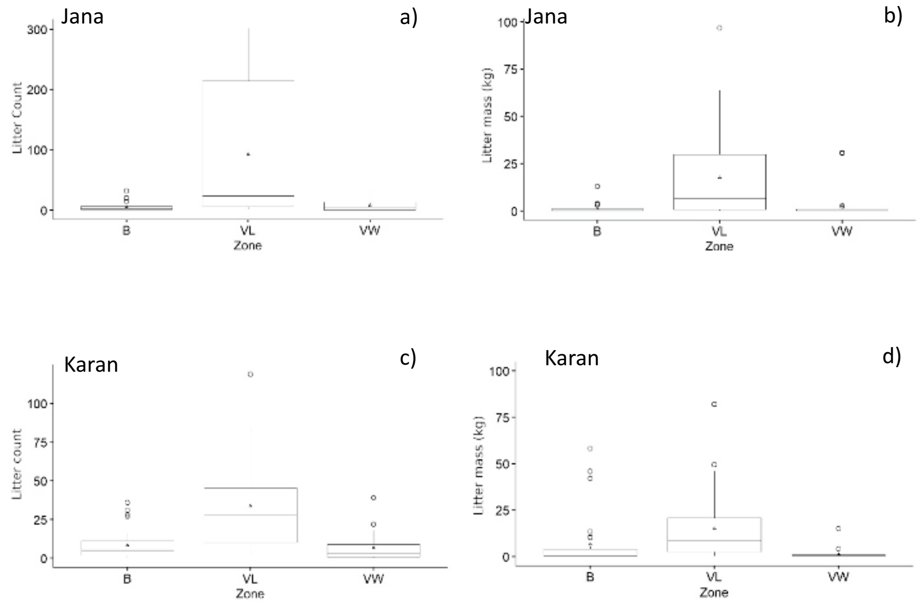

Fig. 4 Box-and-whisker plots of marine debris recorded in October 2020 across three shoreline zones—Beach (B), Vegetation Line (VL) and Vegetation Within (VW)—on Jana (top panels) and Karan (bottom panels) Islands. Panels **a** and **c** display item counts; panels **b** and **d** show total mass (kg). Central lines represent medians, boxes the inter-quartile range (IQR), whiskers 1.5 × IQR, and points outside whiskers are outliers

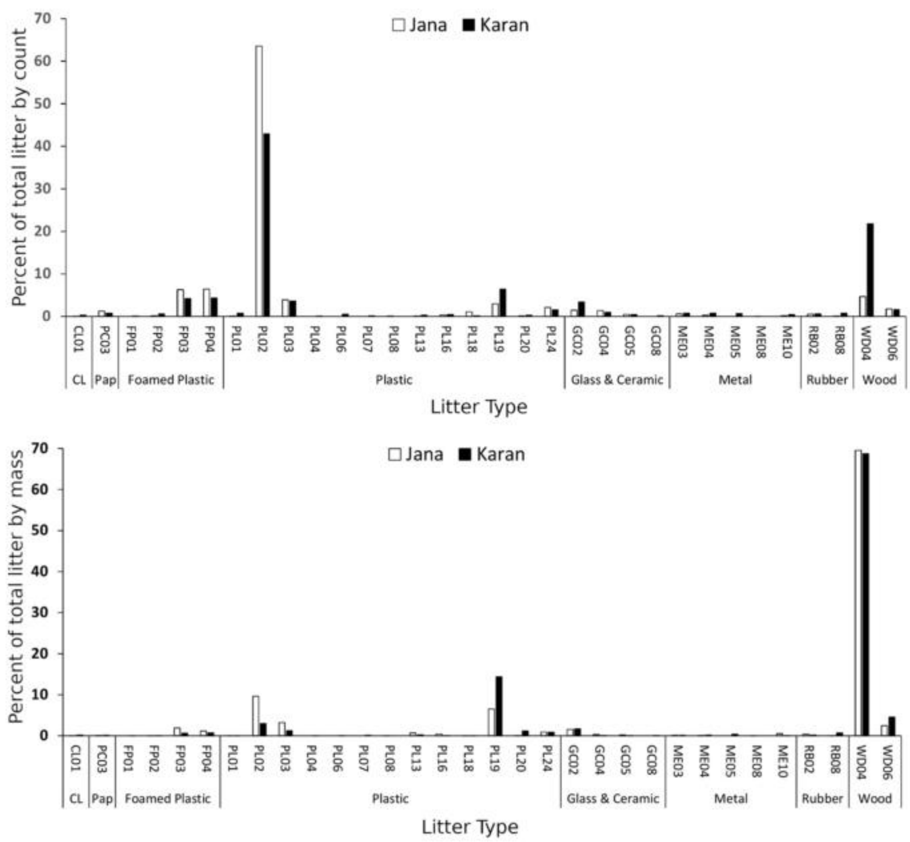

Fig. 5 Relative composition of marine debris recorded in October 2020 on Jana and Karan Islands. Top panel: percentage of total item count by material code; bottom panel: percentage of total mass (kg) by the same material codes

and the occasional drum or bucket. Processed-wood litter, including broken pallets and boat planks, accumulated mainly along the beach and vegetation-line zones.

Processed wood (WD04) and plastic bottles (PL02) were the dominant litter classes on both islands, but they led in different metrics (Fig. 5). Processed wood contributed 69.5% of total litter mass on Jana and 68.8% on Karan, whereas plastic bottles accounted for 63.6% of all items on Jana and 42.9% on Karan. Fishing-related litter—foam buoys (FP03), monofilament line (PL18), rope fragments (PL19) and net pieces (PL20)—represented a small yet notable fraction of the litter assemblage: 8.5% of total mass and 10.4% of items on Jana, and 16.2% of mass and 11.0% of items on Karan.

4 Discussion

The current study highlights the state of marine litter accumulation and distribution in the remote offshore islands within the Saudi waters of the Arabian Gulf combining in situ observations based on photo-quadrats covering the whole islands (in 2017) and intensive shoreline surveys to sample within beach, vegetation line, and vegetation zone (in 2020). Our results provide baseline information on marine litter distribution in offshore islands and the identification of potential coastal point sources based on the location of accumulation zones. Because both Jana and Karan Islands are major sea turtle nesting sites within the Gulf for hawksbill and green turtles, this study expands our understanding of one of the major threats to which the nesting sea turtles are exposed.

A portion of marine litter originating from coastal cities eventually reaches even the most remote offshore turtle nesting islands. Research from the Great Barrier Reef has shown that island beaches accumulate debris irrespective of whether the islands are inhabited, with no significant difference in the amounts deposited on populated versus uninhabited shores [29]. Similarly, highly remote marine-protected islands in the South Pacific accumulate substantial litter, and seabirds there suffer both micro-plastic ingestion and macroplastic entanglement in their nests [30, 31]. As the Gulf cities expand, waste generation and litter outputs will rise [5]. The basin's semi-enclosed configuration and narrow outlet at the Strait of Hormuz [32] create long flushing times, up to three years along the western coast [33], favoring debris retention.

Plastics were the most numerous items on both islands. Globally, plastics make up 60–90% of stranded items on nesting beaches [34–36]. Our bottle-dominated assemblage parallels marine habitats elsewhere in the Gulf [37–39] and mirrors the region's top ten global ranking in bottled-water consumption [8]. Similarly, plastic prevalence is reported for Oman's Al-Wusta wetland [40], inhabited islands in Qatar [41], and Lakshadweep Islands in the Arabian Sea [42]. In the Lakshadweep Islands, hard plastics made up 87% of beach litter type with 45% coming from the fishery sector [42]. The data reflected both consumer-waste and at-sea sources of marine litter. The presence of fishing-related marine litter (fishing nets and foam buoys) points to the possibility that the wider reef flats of the two islands may receive a considerable amount of lost fishing gear and shows that at least some of the gear eventually washes ashore. These lost fishing nets may entangle and cause mortality of multiple stages of sea turtles including breeding adults, juveniles, and hatchlings [43, 44].

The distribution of litter on the shores and their eventual deposition within the interior zones of the islands were influenced by conditions prevailing both at the islands and in the region. Concentration of litter on the western shores of Jana and Karan reflected the south-to-north surface current [32, 45] and onshore Shamal winds, which transport flotsam toward northwestern facing sides of the islands. Urban and industrial centers situated northwest of the islands, as well as vessels transiting the area, offer abundant sources of litter. Large, heavy processed-wood items pile up on the beach face, while smaller, lightweight plastics and foams appear to move inland only where vegetation is sparse. Incursions of lightweight litter such as plastics and foams into the interior differ between islands and appear linked to vegetation structure. The differences in vegetation profiles on the two islands either restrict the litter close to the vegetation line as in the case of Jana Island or allow farther encroachment inside Karan Island where vegetation is sparse and has low profile [16]. Karan's southern interior is sparsely vegetated, allowing wind-driven debris to travel inland, whereas its northern sector is fringed by taller, denser shrubs that act as a barrier. Jana shows the opposite pattern: shorter, more homogeneous vegetation in the north permits deeper inland encroachment, while mixed stands of tall live and dead plants along its central–southern west coast trap debris near the berm. Consequently, the single highest percent cover of marine litter across both islands was recorded on the north-western tip of Jana Island. These results reinforce the role of hydrodynamic and wind forcing in delivering debris to west-facing shores of the studied islands and highlight the vegetation line as the principal retention zone.

The higher the density of marine litter piled up on the nesting beaches, the more impact they pose on both nesting and hatchling sea turtles. Nest distribution surveys have revealed contrasting patterns about the spatial distribution of nests between sea turtle species: hawksbill nests are spread uniformly around Jana's shoreline, whereas green turtle nests on Karan are clustered in the middle and southern sectors and are rare in the north [12, 16]. Continued debris buildup along the western beach sections could restrict future nesting to the few remaining clear stretches of sand, especially for green turtles in Karan. Coupled with the documented, long-term narrowing of both islands' beaches, such crowding may increase density-dependent embryo mortality [14]. Large processed wood materials, often with nails and sharp metal support, prevent sea turtles' access to the upper part of the beach, where the suitable nesting zones are. Light plastic bottles were observed to accumulate into old nest pits dug in the previous nesting seasons, disrupting the ability of nesting turtles to dig out nest chambers. Often, the plastic bottles block the hind flippers of turtles not allowing them to dig a nest chamber (R. H. M. pers. obs.).

The dominance of buoyant bottle fragments in this study and reports from other nesting beaches elsewhere underscore the multiple pathways by which debris threatens the Gulf's sea turtle rookeries. Field trials show hatchlings need two- to three-times longer to cross sand when litter density reaches 6 items per m^2 [13]. The peak density we measured, 4 items per m^2, is close to this reported threshold. The highest density of debris reported in the world's beaches was in the South Pacific with 671.6 items per m^2 [31]. Regional necropsies show that debris ingestion is routine for sea turtles in the Gulf [9–11]. A Saudi Red Sea study also reported plastic ingestion in ≈40% of hawksbill and green turtles examined [46], while even higher prevalence (85%) has been documented for juvenile hawksbill turtles in Abu-Dhabi waters [7].

Marine debris degrades slowly; fragmentation produces microplastics that infiltrate nests and can alter sand temperature profiles [47, 48]. Thermal impacts are particularly critical given that extreme beach temperatures already depress hatching success on these islands [14]. Large wood planks, metal drums, and broken glass further obstruct nesting females, cause injuries, or entangle hatchlings. Global syntheses confirm that high beach litter loads correlate with reduced nesting activity and hatchling-emergence patterns [49, 50], and skewed sex ratios from thermally stressed nests [47]. A global synthesis conducted by Botterell et al. [51] also showed that 45% of surveyed turtle nesting beaches contained microplastics. Given the baseline information on macrolitter values from the current study, examining the levels of microplastic pollution in Jana and Karan Islands and how it affects the island ecosystem is highly recommended, especially in light of growing evidence that microplastics are widespread and under-studied in Saudi marine and coastal environments [52].

Taken together, our results show that vegetation-line trapping and sparse shrub cover, likely influenced by regional wind and hydrodynamics, dictate litter accumulation overlapping with sea turtle nesting zones. Seasonal cleanups of the western vegetation line (before the May–July nesting peak), coupled with bottle deposit return policies and gear-retrieval incentives, emerge as urgent priorities for safeguarding the Gulf's primary sea turtle rookeries. It is expected that renewed accumulation of marine litter will happen regularly over time after beach cleanups. Thus, initiatives to reduce marine litter pollution from the source, particularly along the coastal cities and settlements, will highly likely reduce the accumulation in the remote offshore sites.

5 Conclusions

The two complementary surveys demonstrate that marine litter, overwhelmingly plastic bottles by count and processed wood by mass, now blankets large portions of Jana and Karan, the Arabian Gulf's primary sea turtle nesting islands. Surface currents, Shamal winds and the vegetation line funnel debris onto west facing shores, likely shrinking suitable nesting area and slowing hatchling crawls. Unless litter originating from expanding coastal cities and regional fisheries are curbed, litter loads will keep rising and further constrain these already limited rookeries.

Protecting the islands hinges on an integrated response: routine island-scale assessments to track trends, targeted cleanups of the western vegetation line just before the May–July nesting season, and simultaneous source reduction measures off island such as bottle deposit return schemes, fishing gear retrieval incentives and sustained public awareness efforts. Acting on three fronts mentioned can preserve beach quality and support the long-term recovery of hawksbill and green turtle populations in the Arabian Gulf.

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Author contributions RHM and JDM conceived and designed the study. RHM, AVBF, JFAA, JG, AJ and AUB carried out the field surveys. DLC and AQ coordinated project administration, technical oversight and logistics. RHM performed the data analysis and drafted the manuscript; JDM provided critical revisions. RHM and DLC wrote the final version. All authors reviewed, edited, and approved the final version.

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Data availability All data supporting the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not Applicable.

Competing interests The authors declare no competing interests.

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