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Zooplankton ingestion of microplastics from different transects along the coastal area facing Al Fujairah Emirates (Gulf of Oman, UAE)

Abstract

Microplastics are ubiquitous emerging contaminants in marine environments, with implications for food webs, ecosystems, and human health. This study was conducted on 26 April 2025 to investigate the occurrence and ingestion of microplastics in zooplankton collected from coastal waters of Al Fujairah (Gulf of Oman, UAE), from three transects perpendicular to the shoreline. Each transect represented a site influenced by distinct human activities:(1) agricultural, (2) industrial, and (3) residential impacts. At each site, zooplankton were collected from the water column at three stations with depths of 10 m, 20 m, and 30 m using a 100 µm zooplankton net and preserved in 10% neutralized formaldehyde. In the laboratory, each sample was filtered and washed through 500 µm nylon net, followed by a second filtration through pre-weighed 200 µm nylon net discs. The net discs were dried at 40 °C and weighed to determine the zooplankton biomass (mg). The dried nets with zooplankton were rinsed in Q10 water to remove any residuals, treated with 10% KOH at 40 °C for 24 hours, and the residue was washed with Q10 water and vacuum-filtered through 0.45 µm filters, with a procedural blank run in parallel for quality control. A dual-staining approach using Nile Red and Rose Bengal dyes was employed to distinguish synthetic particles from biological debris on the filters. Suspected microplastics (film-like, rods and spherical particles) were identified under a UV compound microscope. Microplastics were detected in all zooplankton samples with sizes ranged from 25 to 80 µm, and a total of 316 particles recovered, ranging from 11 to 91 per sample and 1.25 to 31.38 particles per mg of zooplankton dry weight. The results confirm widespread contamination of microplastics in the Gulf of Oman coastal area and shallower stations exhibited direct influence by shoreline runoff. Microplastic abundances varied between sites, with the agricultural area exhibiting the highest counts Film-like, rods and spherical particles were the most prevalent morphotypes observed. These findings demonstrate that zooplankton in Al Fujairah's coastal waters routinely ingest microplastics and may represent the first link introducing microplastics to the food web of the studied area as primary consumers. The results are discussed in the context of different human activity sites and prevailing environmental conditions during the study period.

Keywords: gulf of Oman, zooplankton, Microplastics, coastal area, marine ecosystem

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Introduction

Zooplankton occupies the second trophic level in marine food webs, functioning as primary consumers of phytoplankton,[1] facilitating the transfer of energy and nutrients to higher trophic levels. This diverse group includes protozoans and small crustaceans (e.g., copepods and krill, larval fish and gelatinous organism),[1,2] and represents a substantial portion of marine biomass. Due to their ecological role and widespread distribution, zooplankton are effective indicators of environmental change and pollutant exposure.[3,4] Contaminants ingested by zooplankton can therefore magnify through the food web, affecting fish and other predators.[5]

Microplastics (MPs), defined as plastic particles smaller than 5 mm, have emerged as pervasive contaminants in marine environments. Originating from both primary sources (e.g., microbeads, synthetic fibers) and secondary fragmentation of large debris, MPs are now found across all marine environments, from surface waters to sediments.[6] While numerous studies have documented MP ingestion by fish, bivalves, and crustaceans, field- based investigations focusing on zooplankton remain limited despite their ecological importance.[7–12] Coastal research in the United Arab Emirates (UAE), on MPs has primarily targeted sediments and fish, with limited attention to planktonic organisms. MPs have been reported in seawater and sediments along Abu Dhabi's coast and in fish from Dubai's water.[10] However, data from the Fujairah coast, boarding the Gulf of Oman, are scarce. Unlike the semi-enclosed Arabian Gulf, the Gulf of Oman is directly connected to the Arabian Sea and Indian Ocean, exhibiting distinct oceanographic conditions and circulation pattern.[10] These differences underscore the need for baseline assessment of MP pollution in the Fujairah's coastal ecosystems.

Zooplankton distribution is influenced by vertical and horizontal gradients, including diel vertical migration and proximity to coastal activities.[1,2] Their abundance and community composition vary with water quality, nutrient availability, and anthropogenic pressure, making them suitable bioindicator of spatial heterogeneity in marine systems.[9,12] Previous studies in the northern UAE and Oman have shown that calanoid copepods, cyclopoids, harpacticoids, and their nauplii dominate the zooplankton community.[13,14]

This study provides a systematic assessment of microplastic ingestion by zooplankton at Al Fujairah coast (Gulf of Oman, United Arab Emirates (UAE)), focusing on three transects influenced by agriculture, industrial, and residential activities. By quantifying MP ingestion across these sites, the research aims to establish a regional

baseline and explore the relationship between land-based human activities and microplastic contamination in marine food webs.

Material and methods

Study area and sampling design

The study was conducted on 26 April 2025 along Al Fujairah coast (Gulf of Oman, UAE), which differs from other UAE emirates by its open connection to the Arabian Sea and Indian Ocean (Figure 1). Three transects perpendicular to the shoreline were selected, each representing a distinct land-use type agricultural (Transect 1), industrial (Transect 2), and residential (Transect 3). At each transect, zooplankton samples were collected from the water columns of three stations at depths extended to 10 m, 20, m 1ne 30 m. Geographic coordinates for each station are recorded (Table 1).

Table 1 Geographic coordinates of the three sampled Transects and their adjacent land use

Sampling transects	Adjacent land use	Coordinates 10m	Coordinates 20m	Coordinates 30m
Transect 1	Agriculture	N25'26.026	N25'26.026	N25'26.026
		E56'22.290	E56'22.535	E56'22.900
Transect 2	Industrial	N25' 17.017	N25' 17.017	N25' 17.017
		E56'22.719	E56'23.110	E56'23.450
Transect 3	Residential	N25' 08.508	N25' 08.508	N25' 08.508
		E56'21.950	E56'22.677	E56'23.884

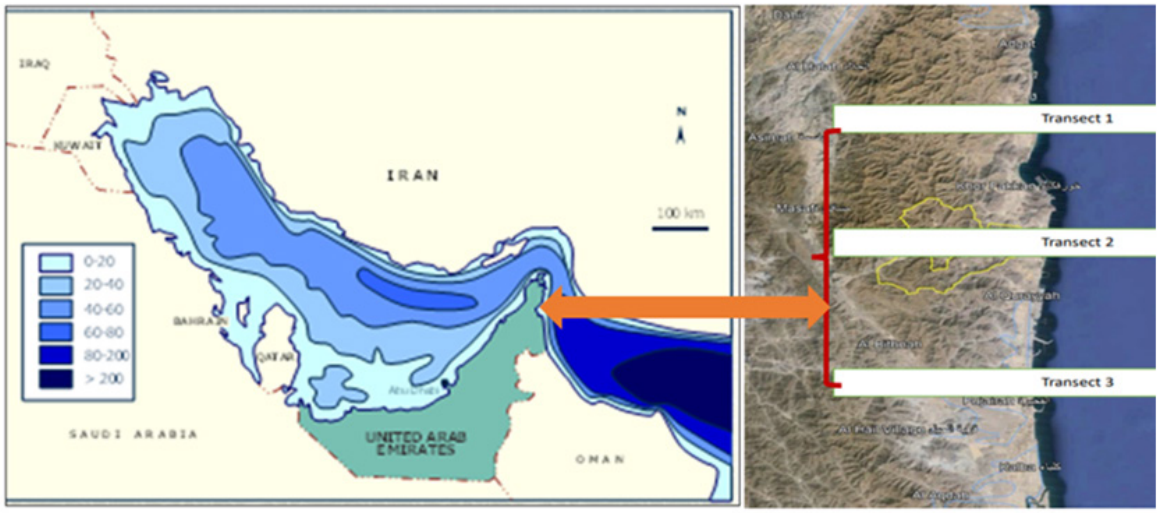

Figure 1 Bathymetric map showing the Gulf of Oman connected to the Arabian Gulf through the Strait of Hormuz (left, modified from Hamza, 2021). The right panel shows the three sampling transects (Transects 1= Agricultural; 2= Industrial; 3= Residential) located along the Fujairah coast, UAE, with approximate locations overlaid on Google Earth Pro imagery.

Environmental parameters measurements

In situ measurements of water temperature, salinity, pH, and Dissolved Oxygen (DO), were taken at 5 meters intervals from surface to near bottom using an Aqua Read 700 multisensory probe. These data provided context for assessing environmental variability across sites.

Zooplankton collection and processing

Zooplankton were collected in duplicate using vertical tows with 100 µm mesh net and preserved in 10% neutralized formaldehyde. In the laboratory, samples were individually filtered through a 500 µm nylon net, rinsed with Milli-Q10 water, and then vacuum filtered through pre-weighed 200 µm nylon net discs. The net discs were dried at 40 °C and weighed to determine the zooplankton biomass (mg dry weight).

Digestion and Microplastic isolation

Dried zooplankton were then rinsed in Q10 water to remove any residuals. The remaining zooplankton on the nylon discs was then digested using a 10% potassium hydroxide (KOH) at 40 °C for 24 h (Figure 2). This protocol, adapted from[15,16] and widely used in biotic microplastic studies,[17,18] effectively dissolves organic matter while preserving the integrity of most polymers.[19] The digested material was vacuum filtered through pre-weighed cellulose nitrate membranes (0.45 µm pore size, 47 mm diameter). The filtration unit was rinsed thoroughly with Milli-Q water between samples to prevent cross-contamination.[20] Retained residues on filters were dried at 40 °C and stored in sterile Petri dishes for staining and analysis.[21]

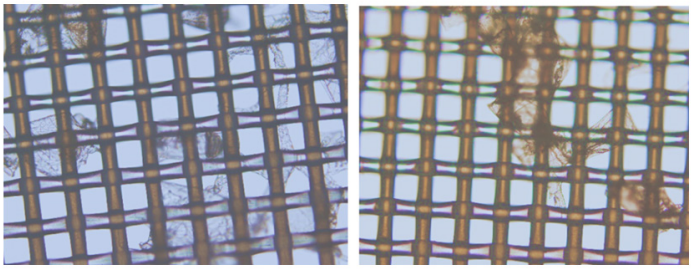

Figure 2 Microscopic pictures of the digested zooplankton retained on the Nylon net discs.

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Staining and Microscopic analysis

A dual staining protocol was used to differentiate synthetic particles from organic debris.[22] Filters were treated with Nile Red (1µg / ml in acetone) following,[22] to fluoresce synthetic polymers under UV light, followed by Rose Bengal (200 mg/L in Milli-Q water), to stain organic matter. Filters were examined under a compound microscope, and microplastics were identified based on fluorescence, morphology and absence of Rose Bengal staining.

Microplastics identification and counting

All Stained filters were analyzed under a UV light compound microscope. Fluorescent particles were visually inspected and counted (Figure 3). To ensure accuracy and minimize contamination, procedural blanks (Mill-Q water processed identically through digestion, filtration and staining) were run in parallel. Any particles resembling those found in blanks were excluded from sample counts. Fibers were excluded from analysis due to their high risk of airborne contamination.[22,23] During the samples analysis strict contamination control protocols were followed through.[18,24] The analyses were performed under strict rules of contamination control. Glassware was rinsed with ethanol and Milli-Q water and kept covered with aluminium foil when not in use. All solutions were prepared using pre-filtered Milli-Q water.

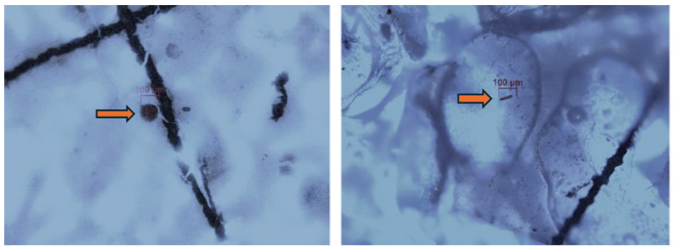

Figure 3 Photographs of Microplastics extracted from digested zooplankton under a fluorescent microscope, showing MP bead (left) and MP rod (right). All detected MP particle sizes were less than 100 µm.

Results

Environmental parameters

During the sampling campaign, weather and sea conditions were suitable for marine research. Wind speed ranged from 6-8 km/h, blowing from southwest under cloudless sky, with air temperature around 35°C and relative humidity at 42%.

In situ measurements of water temperature, salinity, pH, and dissolved oxygen (DO) were recorded at different stations with depths 10 m, 20 m, and 30 m depths across the three transects. In the agricultural transect, water temperature ranged from 24.2 °C near the bottom to 29.1 °C at the surface, while pH ranged from 7.91 to 7.98, DO ranged from 7.28 to 10.31 mg/l, and salinity ranged from 34.14 to 35.25 PSU. On the other hand, at the industrial site, temperature ranged between 24.1 °C near the bottom and 29.6 °C at the surface, pH from 7.93 to 8.01, DO from 5.84 to 11.24 mg/l, and salinity from 34.58 to 35.95 PSU. In the residential transect, temperature varied from 26.4°C near the bottom to 30.0 °C at the surface, pH from 7.95 to 8.02, DO from 7.09 to 9.65 mg/l, and salinity from 34.65 to 35.99 PSU. Overall, temperature was consistently higher at shallower depths (10 m) across all transects, reflecting typical coastal thermal gradients. pH values remained within a narrow alkaline range (7.9–8.0), while salinity showed minimal variations. In contrast, DO exhibited greatest variability, with the agricultural transect recording the highest concentrations (10.31 mg/l), compared with the industrial and residential sites (Figure 4).

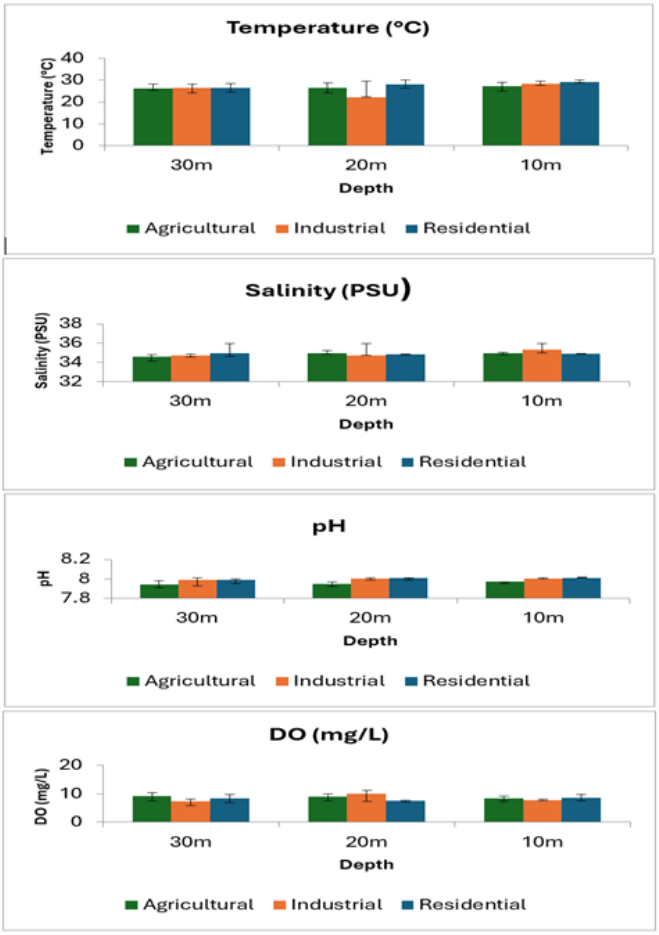

Figure 4 Averages and ranges of environmental parameters measured in situ at the different depth stations of the three transects.

Microplastics in Zooplanktons

Microplastics were detected in all zooplankton samples collected from agricultural, industrial, and residential transects at stations with depths of 10 m, 20 m, and 30 m. Across the nine samples, a total of 316 microplastic particles were identified with sizes ranged between 25 and 80 µm (Figure 3). The highest abundance was recorded at the agricultural transect (91 particles), while the lowest was recorded at the residential transect (11 particles).

Microplastic ingestion per milligram of zooplankton dry weight ranged from 1.25 to 31.38 particles/mg. Agricultural samples again exhibited the highest values, peaking at 31.38 particles/mg at the 10 m depth station, while industrial samples ranged between 2.34 and 7.32 particles/mg, and residential samples between 1.25 and 3.14 particles/mg (Figure 5). The estimated standard deviations of microplastic particles ingested per 1 mg dry weight varied significantly across depths, with the greatest variability observed at the 10 m stations compared to those at 20 m and 30 m (Figure 5).

Beads were the most frequently encountered particle type, followed by film-like rod- shaped particles. These morphotypes were consistently observed across all sites and depths (Table 2).

Overall, the agricultural transect exhibited the highest microplastic concentrations. In contrast, the residential transect showed lower

microplastic loads but higher zooplankton biomass indicating reduced anthropogenic impact and significant spatial variability in zooplankton exposure to microplastic pollution along the Al Fujairah coast (Table 2).

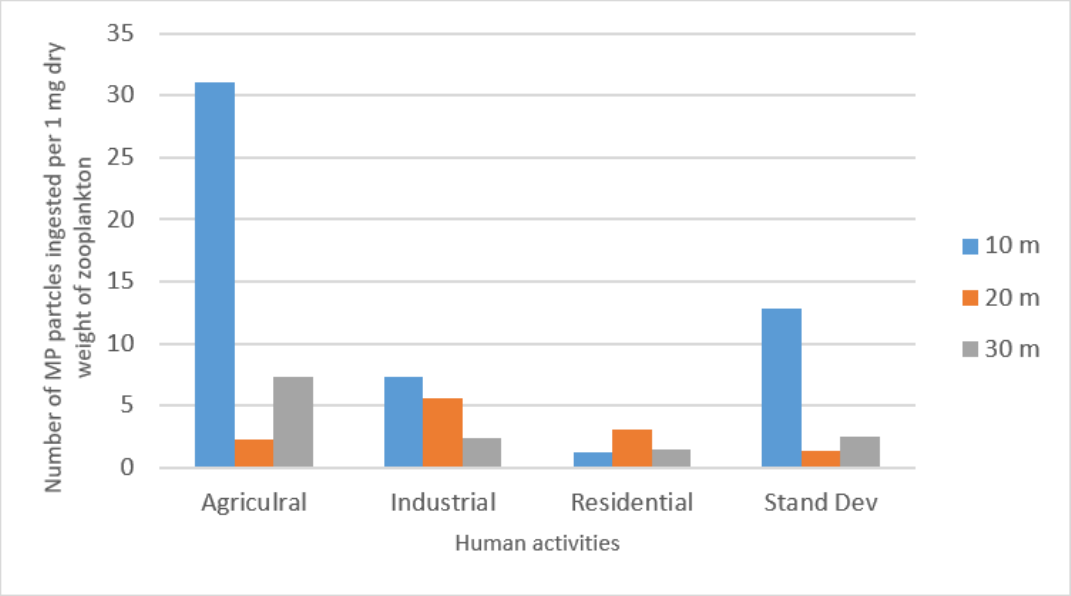

Figure 5 Average number of microplastic particles ingested per 1 mg of zooplankton dry weight at each station depth across the three transects influenced by different human activities along the coast of Al Fujairah Emirate (UAE), with calculated standard deviations (Stand Dev) for each depth.

Table 2 Microplastics (MPs) abundance and quantity ingested by zooplankton unit (mg dry weight) from the different stations along the Al Fujairah coast

Sampling site type	Depth	Net Filtered Volume m^3	No. MPs Films	No. MPs Beads	Total MPs	Zoopl. Dry Weight	F+B/ ZDW	F/ZDW	B/ZDW
	m		F	B	F+B	ZDW (mg)	No/mg	No/mg	No/mg
Agricultural	10	1.413	3	88	91	2.9	31.38	1.03	0.34
	20	2.826	3	9	12	5.3	2.26	0.57	1.7
	30	4.238	3	43	46	6.3	7.3	0.48	
Industrial	10	1.413	9	43	52	7.1	7.32	1.27	6.06
	20	2.826	2	41	43	7.7	5.58	0.26	5.32
	30	4.238	5	13	18	7.7	2.34	0.65	1.69
Residential	10	1.413	6	5	11	8.8	1.25	0.68	0.57
	20	2.826	15	12	27	8.6	3.14	1.74	1.4
	30	4.238	2	14	16	10.8	1.48	0.19	1.3

Discussion

Coastal zones are exposed to various pollutants originating from local human activities. Additionally, pollutants may arrive from neighboring coastal waters or adjacent seas, depending on water current direction and its intensity. In the last decades, microplastics (MPs) have become a global environmental problem. MP pollution has many potential sources, such as industry, agriculture, landfill, wastewater treatment plants, household waste, tires, synthetic textiles, and packaging materials.[25] These sources have reached aquatic environments in diverse ways, such as direct discharge through terrestrial effluents and aquatic activities, or indirectly through weathering and aerosol deposition. Many researchers have proven the presence of MPs in water columns, living aquatic organisms, and in sediments of aquatic basins.[26,27] Research on MPs has gone beyond the record of microplastics in various tissues, such as fish muscles, gills, and liver; they identified the size, forms, and chemical structures of such polymers.[27] The ingestion of MPs by aquatic organisms varies; MPs may be freely suspended in water and passively ingested. MPs may also be embedded in food items, retained in body tissues, and subsequently transferred to higher trophic levels. Moreover, the densities of MPs in the body of aquatic organisms depend on the feeding habits, the type of food, and the intensity of MPs in the surrounding environment or the habitat. Such information has been collected and mentioned in different research and review articles.[28,29,30] Researchers have increasingly focused on the trophic transfer of MPs and quantifying their accumulation in higher trophic levels. However, most of the research was conducted under laboratory conditions,[31] while a few were conducted directly in the aquatic environment.[32] In this respect, this research attempted to investigate the relationship between the adjacent land use and the introduction of MPs to the Food web through the second trophic level, which is represented by the zooplankton as the primary consumer in the Gulf of Oman ecosystem along the coastal area of the Al Fujairah Emirate (UAE). The selected three transects correspond to the land using human activities, where their residuals are discharged to the coastal water either directly by

municipal effluents or indirectly through weathering and maritime activities. The measured environmental parameters have indicated a higher temperature at the 10 m depth stations compared to the 30 m depth stations in all transects. This reflects a typical oceanographic pattern where shallow coastal waters absorb heat from adjacent land masses. While water salinity and pH values have shown minimal variations between different stations of the three transects, which could be due to the time of measuring during the day, the DO values have shown maximum values (10.31 mg/l) at the agriculture transect. These high values of DO could be a result of discharging freshwater from the farms or due to the water circulation pattern in the area, since the agriculture transect is located at the northern side of the Al Fujairah coastal area, which receives the underlying water layer exiting from the Arabian Gulf and moves southward along the Al Fujairah due to tidal currents.[13]

In the present study, the highest zooplankton biomass was also found along the residential transect, and the highest number of MPs particles was found at the Agricultural transect, while the industrial area showed intermediate zooplankton biomass and higher numbers of MPs compared with the residential transect. These results suggest that agricultural activities contribute more MPs than industrial or residential sources. In their studies,[25,33,34] they found that the sources of MPs in agricultural soils can be added through many farming activities. The common applications of polyethylene (PE) plastics in agriculture are greenhouses as permanent cover materials; mulching films to control temperature and moisture; and plastic irrigation tubes. In addition, large plastic items that are present in soil gradually become small fragments and MP particles due to various environmental weathering processes, mechanical breakdown, decomposition, and photo-degradation. They also added that the sludge manure contained different microplastic compositions reflecting the various sources of the sludge. Microplastic abundance increased by 723–1445% following sewage sludge applications.[34,35] Indeed, elevated microplastic concentrations at 10 m depth of the agricultural transect suggest direct influence from shoreline runoff.

In addition to agricultural sources, transboundary currents from the Arabian Gulf may transport MPs to the Gulf of Oman via the Strait of Hormuz. While the high number of MPs found the industrial transect could be a result of the new oil transportation and related to its industrial activities, which happened after the translocation of the United Arab Emirates its export oil harbor from Abu Dhabi (inside the Arabian Gulf) to Al Fujairah harbor (Gulf of Oman) in 2024. However, the small number of MPs and the high zooplankton biomass at the residential transect can be simply attributed to the low density of inhabited houses as well as coastal irregularity, which renders the location isolated from industrial influences.

The present study can be considered as a snapshot of the studied area under specific weather and sea conditions. However, as a dynamic system, each moment may present a different picture of the interactions occurring between various trophic levels in the food web. In this regard, future studies should consider seasonal variabilities, weather, and sea conditions, when conducting in situ research. Furthermore, the absence of standardized methods for tracking microplastics (MPs) through aquatic food webs has led researchers to develop customized protocols tailored to specific study objectives. In this study, we integrated steps from various published protocols to address our study objectives. To better quantify the contribution of each trophic level to MP ingestion, we propose the development of mesocosm experiments (in vitro or in situ) incorporating fluorescent microplastic beads. These suggestions may contribute to ongoing or future studies aimed at providing a better understanding and insight into MP transfer between trophic levels in aquatic food webs. An additional suggestion could be fingerprinting of land use polymers and linking them to the existing coastal industrial, agricultural and commercial activities. This may help in identifying its source and help decision makers to take proper action.

Conclusion

In this study, our findings demonstrated that coastal human activities, along with natural factors, influence MP pollution levels. Zooplankton, particularly copepods, may serve as an indicator of MP concentrations across sites with varying anthropogenic pressure.

Despite these insights, a critical question remains : what portion of Mps in aquatic food webs originates from zooplankton ingestion ? Addressing this will require robust methodologies capable of tracing Mps across trophic levels. By quantifying Mps in primary consumers, our study fills a regional gap and contributes to broader efforts in marine pollution monitoring and policy development in UAE.

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Conflicts of interest

The authors declare no conflicts of interest.

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