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Do feeding habits influence anthropogenic particle consumption in demersal fish in a tropical estuary? A study from the northern part of the Tropical Eastern Pacific

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Introduction: The presence of anthropogenic particles (AP), defined as materials that have undergone human modification, in an estuarine system, and their consumption by demersal fishes, were assessed in the northern part of the Tropical Eastern Pacific. The aim was to investigate how the type and quantity of microplastics ingested by demersal fish of different trophic levels, feeding habits, and feeding guilds vary, and if these relate to the APs found in water.

Methods: Water and fish samples were collected from a network of stations through the estuarine system of Huizache-Caimanero. The presence and characteristics of microplastics were analyzed using Fourier Transform Infrared (FTIR) spectroscopy. A total of 1,162 AP particles were identified in the water samples, with fragments being the most common form. Stomach contents from 133 fish, representing six species across different trophic levels and feeding habits, were examined. These species included planktivores, carnivores, and omnivores, as well as zoobenthivores, piscivores, planktivores, and detritivores.

Results: The study found a high frequency of microplastic ingestion among fish, with fibers being the most prevalent form. The most common polymers identified in both water and fish were cotton and polyethylene terephthalate (PET). Other polymers detected included alkyd resins in water and nylon in fish, while polyethylene and acrylic were less abundant. These findings align with the types of human activities conducted in the study area.

Discussion: Our findings suggest that the position in the water column influences microplastic ingestion, rather than trophic position or feeding habits. This study provides valuable insights into the impact of AP contamination on coastal ecosystems and highlights the need for effective management strategies to mitigate its effects. Future research should focus on the long-term ecological impacts of microplastics and the development of sustainable solutions to address this growing environmental challenge.

KEYWORDS

FTIR, trophic guild, microplastic pollution, Mexico, cotton fibers, gastrointestinal content

1 Introduction

Marine litter, particularly plastic, is a significant environmental challenge affecting marine ecosystems (De-la-Torre et al., 2021; Haarr et al., 2022). Litter enters marine ecosystems whether deliberately or accidentally from land-based sources like plastic manufacturing plant effluents, urban runoff, sewage discharges, and recreational activities (Jambeck et al., 2015; Rech et al., 2014), as well as from aquatic activities such as fishing and aquaculture (Campbell et al., 2017), affecting sea, shorelines, and beaches, Once in the aquatic ecosystems, this litter accumulates globally, from coastal areas to deep waters.

Particularly, plastic pollution has become the most prevalent form of marine litter due to its high demand and production levels (Haarr et al., 2022). The world plastic production in the year 2023 was 413.8 million tons (Plastics Europe, 2024), increasing from previous years, and recent estimations indicate that 11% of this production could end up in the aquatic environment (Borrelle et al., 2020). Mexico is one of the main producers of plastic waste worldwide, ranking in the top five globally (World Population Review Plastic Pollution by Country 2024, 2025), with an average per-person plastic consumption of 66 kg/plastic per year, and an average per capita plastic waste generation of 43 to 59 kg/person per year. From this quantity, it is estimated that 7 to 15% could leak into the environment, the rivers being the main contributors to plastic pollution in the ocean (Vázquez-Morillas et al., 2024).

Considering that rivers are the main way for plastics to reach the ocean, estuarine systems with associated mangrove forests, as the interface between rivers and the ocean, are particularly susceptible to function as accumulation regions and sinks of litter, retaining waste in the mangrove vegetation for long periods (Núñez et al., 2019; Tramoy et al., 2020). Additionally, tropical estuarine systems have population densifications due to their high productivity and, as a result, a wide variety of ecosystem services, such as fisheries support, recreational values, carbon sequestration, and coastal protection (Barbier et al., 2011), making them economically important for the livelihoods of people inhabiting the areas close to these systems, but also environmentally vulnerable, being at present highly threatened socio-ecological systems (Campos-Silva and Peres, 2016). These coastal areas are usually altered for different purposes and converted into aquaculture ponds or agricultural fields (Richards and Friess, 2016). As a consequence, these areas contain a large amount of litter (Duarte et al., 2023; Mazarrasa et al., 2019; Núñez et al., 2019) that is likely to enter the trophic chain (Lusher et al., 2017).

Microplastics (plastic particles < 5 mm) are the most common type of plastic found in the marine environment (Lusher et al., 2020; Martin et al., 2017), in the form of fibers or particles, fibers being the most prevalent form (Claessens et al., 2013). As they resemble prey items that can be mistaken for food by organisms in the environment (Wang et al., 2020), microplastic ingestion by a wide type of marine taxa from different trophic levels has been documented, particularly in the form of microfibers (Lusher et al., 2013, 2017; Possatto et al., 2011; Romeo et al., 2016; Ryan et al., 2009). For the specific case of the studied area, the presence of microplastics in fish has been documented in estuarine systems in the Gulf of California (Malthaner et al., 2024; Pinho et al., 2022; Salazar-Pérez et al., 2021), and in the studied system, the presence of microplastics has been reported in the gills, exoskeleton, and gastrointestinal tract of shrimps (*Litopenaeus vannamei* (Boone)) (Valencia-Castañeda et al., 2022).

Anthropogenic particle contamination in fish has been observed in tropical marine and coastal regions (Dantas et al., 2020; Ferreira et al., 2016, 2018; Justino et al., 2021; Malthaner et al., 2024; Pinho et al., 2022; Salazar-Pérez et al., 2021). However, research on the link between the presence of anthropogenic particles in the water column, fish feeding habits, and trophic guilds is limited, and in regions such as the northern part of the tropical eastern Pacific, nonexistent. This information is crucial for comprehending how the marine environment and its organisms will ecologically react to the effects of plastic pollution. It also helps to understand the bioaccumulation process of microplastics in marine species, which is significantly affected by their feeding strategies (Miller et al., 2020). They also serve to understand and predict the impacts of contamination on coastal and marine ecosystems. With this in mind, this study aims to analyze microplastic contamination in demersal fishes in an estuarine system from the northern part of the Tropical Eastern Pacific and investigate how the type and quantity of microplastics ingested vary based on the trophic guild and feeding behavior.

2 Materials and methods

2.1 Sampling site and procedures

The research was carried out in the estuarine system of Huizache–Caimanero (22.831685°, 106.030473° to 23.092533°, 106.291138°), a shallow intermittent estuary heavily influenced by freshwater inputs from the Presidio and Baluarte rivers (Figure 1) (Amezcua et al., 2019). These rivers are connected to coastal lagoons through narrow tidal channels surrounded by mangrove forests. This coastal system receives ample freshwater during the rainy season (June to November), which mixes with the seawater from the ocean, creating a typical estuarine circulation pattern, and making the average area of the system 175 km^2, which during the dry season reduces to 65 km^2. Both rivers receive discharges from rural, agricultural, semi-urban, and aquaculture sources (Valencia-Castañeda et al., 2022). This ecosystem is also under human impact as it supports diverse small-scale fisheries (Ramírez-Rodríguez et al., 2014), and the landscape has undergone significant environmental changes due to the expansion of agriculture and aquaculture in the floodplain and margins of the lagoon in recent decades (Valencia-Castañeda et al., 2022).

A network of stations was established along the estuarine system (Figure 1) to study the connection between anthropogenic particles in water and those ingested by fish. At each station, water and fish samples were taken during morning hours and high tide between October 2022 and November 2023 at every one of the three climatic seasons in the area: dry cool season (DCS, from December 1st to March 31st), dry warm season (DWS, from April 1st to June 30th), and humid warm season (HWS, from July 1st to November 30th), as defined by Amezcua et al. (2019), using skiffs equipped with 15 hp outboard engines, a submersible pump, a gillnet with a mesh size of 3.5 inches, and a cast net with a mesh size of 0.6 inches. Water samples were obtained using a submersible pump and filtered through a 63-µm metallic sieve on-site. The filtered water was then transferred to glass jars and transported in a cooler to the laboratory for analysis. Fish were captured by local fishers holding a fishing concession for this estuarine system issued by the Ministry of Rural Development and Agriculture, and the National Commission for Fisheries and Aquaculture of Mexico. Gillnets were used in stations exceeding a depth of 1.5 m, and it was left adrift at each station for 60 minutes. In stations with depths below 1.5 m, a cast net was used. The captured fish were placed in labeled plastic bags and transported in a cooler.

2.2 Preparation of materials and work area

Necessary precautions were taken to prevent contamination from external sources of Potential Anthropogenic Particles (PAP) before analyzing water samples and the gastrointestinal tract of fish to extract PAP. The following measures were implemented: a) Access to the work area was restricted; b) Plastic materials were avoided near the samples, and wearing cotton lab coats was required; c) Glassware, caps, and Whatman® filters (Whatman International

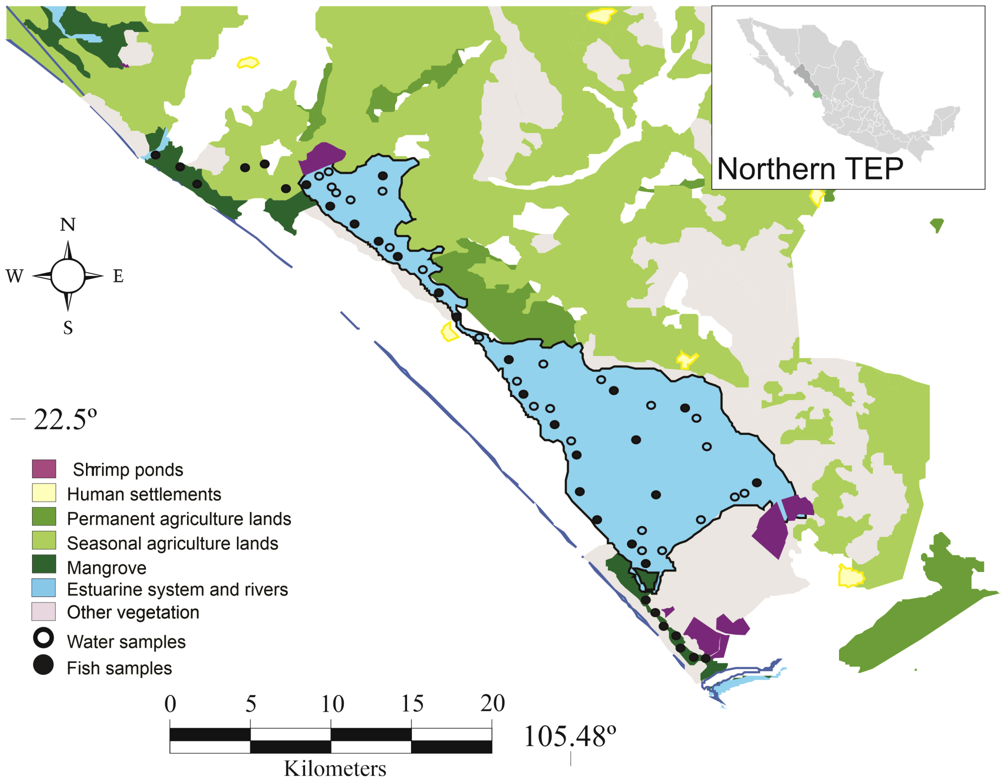

FIGURE 1
Sampling stations at the Huizache-Caimanero estuarine system. Urban settlements and anthropogenic activities in the area are indicated.

Ltd., Mainstone, UK) underwent pre-treatment in an oven at 400°C for 4 hours. In addition, weighing dishes and dissection equipment were cleaned with methanol, acetone, and distilled water filtered through a 1.2 µm Whatman® GF/C glass fiber filter; d) Clean Petri dishes containing distilled water were placed in the work area for each sample set as a blank at each step. These dishes remained open during sample exposure to the environment.

In total, five control blanks were processed at different time points during sample handling within the restricted area of the laboratory. These include dissection, filtration, and filter inspection under a stereomicroscope. The number of particles detected and their corresponding materials are listed in Supplementary Table 1.

2.3 Fish dissections and stomach content analysis

Each fish specimen was measured for total length (mm) and body mass (g) with an accuracy of 1 mm and 0.1 g, respectively. The stomach and intestinal organs of each individual were carefully removed through a longitudinal incision from the cloaca to the esophagus, weighed, and stored for future analysis and digestion. The gastrointestinal tract contents were placed on a Petri dish and examined visually using a stereomicroscope (Zeiss Stemi 508). Any PAP were isolated, and prey items were counted and identified to the most specific taxonomic level possible. If items were too digested to be counted but still recognizable as belonging to a large taxonomic group, they were categorized as 'remains' and weighed together. For partially consumed prey, individual numbers were estimated based on countable parts like claws, legs, otoliths, or beaks, considering size and shape to determine that they came from the same individual (Muro-Torres et al., 2023). They were then categorized based on their ecological characteristics. The stomach and intestinal lining were scraped and washed to collect suspected plastic particles and prey items. The materials were then placed on a heating plate for further analysis. The trophic position (TP) of the most abundant species caught was determined using references specific to the study area (Amezcua et al., 2015; Muro-Torres et al., 2019, 2022). Feeding guilds were assigned based on TP and food preferences (dominant items in the diet) following the methodology outlined by Dantas et al. (2020), and TP and trophic guilds were taken from the study of Muro-Torres et al. (2020), which was undertaken in an estuarine system next to our studied area. Six species with different TP, feeding habits, and feeding guilds were chosen for this study, each with a minimum sample size of 20 individuals. The sample size exceeds the recommended number to prevent bias from a small sample size (Markic et al., 2020).

2.4 Chemical digestion for water and fish samples

The prey items were separated, and each gastrointestinal tract was placed in a glass jar for chemical digestion. Each water sample and each gastrointestinal tract of fish were digested to remove all organic matter using 20% (w/v) potassium hydroxide (KOH) in a 3:1 ratio. The samples were then incubated at 40°C ± 5°C for 24 hours. Afterward, 30% hydrogen peroxide (H_2O_2) (5 to 10 ml) was added at room temperature and left for an additional 12 hours to clarify the sample and remove any remaining organic matter. The digested samples were filtered using a vacuum pump filtration system with Whatman® GF/C 1.2 µm glass fiber filters. The filters were dried at 45°C ± 5°C in glass Petri dishes covered with aluminum foil. Finally, the filters were examined under a stereomicroscope (Zeiss Stemi 508, Carl Zeiss Microscopy GmbH, Jena, Germany) to separate and characterize AP by type (fragment or fiber), color, and size.

2.5 FTIR spectroscopy

The material composition of all the AP found in both water and the gastrointestinal system of fish was analyzed using Fourier-transform infrared spectroscopy (FTIR) with a Thermo Scientific™ Nicolet™ iN™10 infrared microscope. Sample readings were taken at a pressure of 15–25 psi and an aperture of 50 × 50 µm. The FTIR-ATR spectrum was an average of 16 scans from 650 to 4000 cm^{-1} with a resolution of 4 cm^{-1}. Microplastics were identified by comparing them to standard polymers in the FTIR spectrometer library, with a minimum match threshold of 75% for all samples.

2.6 Data analysis

One-way analyses of variance (ANOVA) were used to test for differences in the mean number and length of AP in water samples from the two analyzed lagoons (Huizache and Caimanero), to determine spatial differences, and the mean number and length of the AP per fish species. Before the analysis, the homogeneity of variances was assessed using Cochran's C test. *Post-hoc* pairwise mean comparisons were conducted using Tukey's HSD test, in case differences exist.

To test the null hypothesis (H_0) that prey and microplastic ingestion do not vary by species, locality, feeding habits, TP, and trophic guild, a permutational Multivariate Analysis of Variance (PERMANOVA) was conducted (Anderson et al., 2008). Two matrices were created, one with the relative abundance of prey items and the other with the relative abundance of microplastic polymers as rows, and each fish individual as columns. To account for variations in gut content among individuals, the data were sample-standardized (Malthaner et al., 2024). The standardized data were then expressed as a percentage composition of each prey and microplastic category, with each column totaling 100. Bray–Curtis similarity matrices were then generated with species, trophic guild, and TP as factors.

Principal coordinates analysis (PCO) was used in the case of significant differences (Anderson et al., 2008). This method is very flexible as it can be based on any resemblance matrix. However, it is a projection of the points onto axes that minimizes residual variation in the space of the chosen resemblance measure. APs were overlaid as vectors on the PCO to assess their importance. The trajectory of the vectors indicates the significance of each polymer in the different fish species' diets. The axes range from -n to n, with the centroid at 0, 0 representing no difference in prey or microplastic items based on established factors (Malthaner et al., 2024). Fish with empty stomachs were excluded from the analysis. Statistical analyses were performed in Primer 7 with the PERMANOVA add-on (License number 7875).

3 Results

3.1 Water results

A total of 1,162 AP particles were identified in the water samples, all displaying typical AP shapes observed under a stereomicroscope, with 61% being fragments and 39% fibers (Figure 2). Concentrations ranged from 0 to 110 AP/L, with an average of 50.5 ± 28.1 AP/L. The highest concentration of AP was found in the northern lagoon (Caimanero) with an average of 51.9 particles, compared to 47.4 in Huizache Lagoon. However, there were no significant differences in the mean number of AP particles between the two lagoons (F1,21 = 0.117, p>0.05). The average length of AP particles was larger in Huizache lagoon (0.64 mm) compared to Caimanero lagoon (0.45 mm), but these differences were not statistically significant (F1,21 = 0.676, p>0.05).

3.2 Fish analysis

A total of 133 stomach contents of six selected fish species from the estuarine system of Huizache-Caimanero were analyzed. A minimum of 20 individuals per species were analyzed, following the recommendations of Markic et al. (2020), for a meaningful analysis. The fishes were demersal and benthopelagic species with different trophic and feeding guilds, as well as different TP according to Muro-Torres et al. (2020), from the first-order consumer persistent anchovy (*Anchoa walkeri*, Baldwin & Chang) to the system top predator, the orangemouth weakfish (*Cynoscion xanthulus*, Jordan & Gilbert). Trophic guilds included planktivorous (persistent anchovy), carnivorous of different orders (Carnivore 1: Tete sea catfish, *Ariopsis seemanni* (Günther); Carnivore 2: Yellowfin snook, *Centropomus robalito*, Jordan & Gilbert; Carnivore 3: orangemouth weakfish), and the omnivore white mullet (*Mugil curema*, Valenciennes). Feeding guilds included mainly zoobenthivores (tete sea catfish, yellowfin snook, and the orangemouth weakfish), and from these two were also considered piscivores (yellowfin snook and orangemouth weakfish), one planktivore (persistent anchovy), and one detritivore (white mullet) (Table 1). All these species have commercial importance in the area (Ramírez-Rodríguez et al., 2014)

In total, 235 APs were found. Of these, 214 were fibers (approximately 91%), and 21 were fragments (almost 9%) (Figure 2). APs were present in 93 fishes out of 133 (69.9%) and all the analyzed species. The APs ranged in length from 0.07 mm to 11.2 mm with a mean length of 1.25 mm, indicating that the majority can be considered microparticles. The abundance per individual varied from 0 to 11, with a mean number of AP per individual of 1.8. The frequency of occurrence per species varied from 60.7 in the orangemouth weakfish to 100 in the Tete sea catfish, and in all the species, AP were found.

The results of the one-way ANOVA testing for differences in mean abundance and mean length of the different species indicated that the detritivore/omnivore white mullet had a higher average particle ingestion compared to the Tete sea catfish (F4,122 = 3.73, p<0.05; Figure 3A). However, no significant differences were found between any of the other species. In terms of length, the planktivore persistent anchovy ingested the largest AP on average ($F_{4,122}$ = 3.2, p<0.05; Figure 3B), and these differences were significant only with the mean length of AP ingested by the Tete sea catfish, which ingested the lowest number and the smallest AP on average.

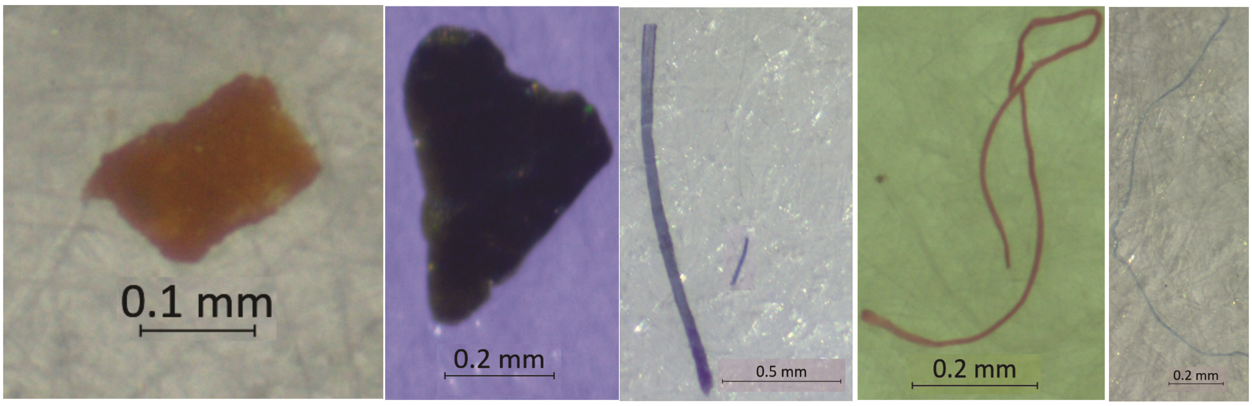

FIGURE 2
Representative images of the most abundant fragments and fibers found in the gastrointestinal tracts of juveniles of the analyzed fish species.

TABLE 1 **Ecological parameters, biometry, and occurrence of anthropogenic particles in representative demersal fish species from an estuarine system in the northern TEP.**

Taxa		Ecological parameters				Biometry		Anthropogenic Particles occurrence					
Family	Species	N	TP	TG	FG	TL	Mi-Mx	NFWAP	FO	MNAPS	Mi-Ma	APLMean	APLMi-Ma
Engraulidae	*Anchoa walkeri*	30	1.29	Plank	P	10.18	6.2-20.2	19	63.3	2.1	0-6	1.71	0.15-11.2
Aridae	*Ariopsis seemanni*	20	3.18	Car 1	ZB	26.16	8.8-55	20	100	1.6	0-11	1.03	0.09-12.8
Centropomidae	*Centropomus robalito*	31	2.73	Car 2	ZB/ PV	17.67	4.5-27	23	74.2	3.8	1-3	1.39	0.1-4.4
Scianidae	*Cynoscion xanthulus*	28	4.27	Car 3	ZB/ PV	24.39	6.6-36.5	17	60.7	1.3	1-2	1.05	0.07-4.39
Mugilidae	*Mugil curema*	24	1.95	Omn	D	22.8	5.3-34	14	58.3	0.5	0-2	1.27	0.12-8.5

TP, Trophic position; TG, Trophic Guild (Car, Carnivore; Plank, Planktivore; Omn, Omnivore); FG, Feeding guild (P, Planktivore; ZB, Zoobenthivore; PV, Piscivores; D, Detritivore); TL, Total length (cm); NFWAP, number of fish with AP; FO, frequency of occurrence of AP; MNAPS, mean number of AP per specimen; APL, Length of AP (mm). Mi, min; Ma, Max.

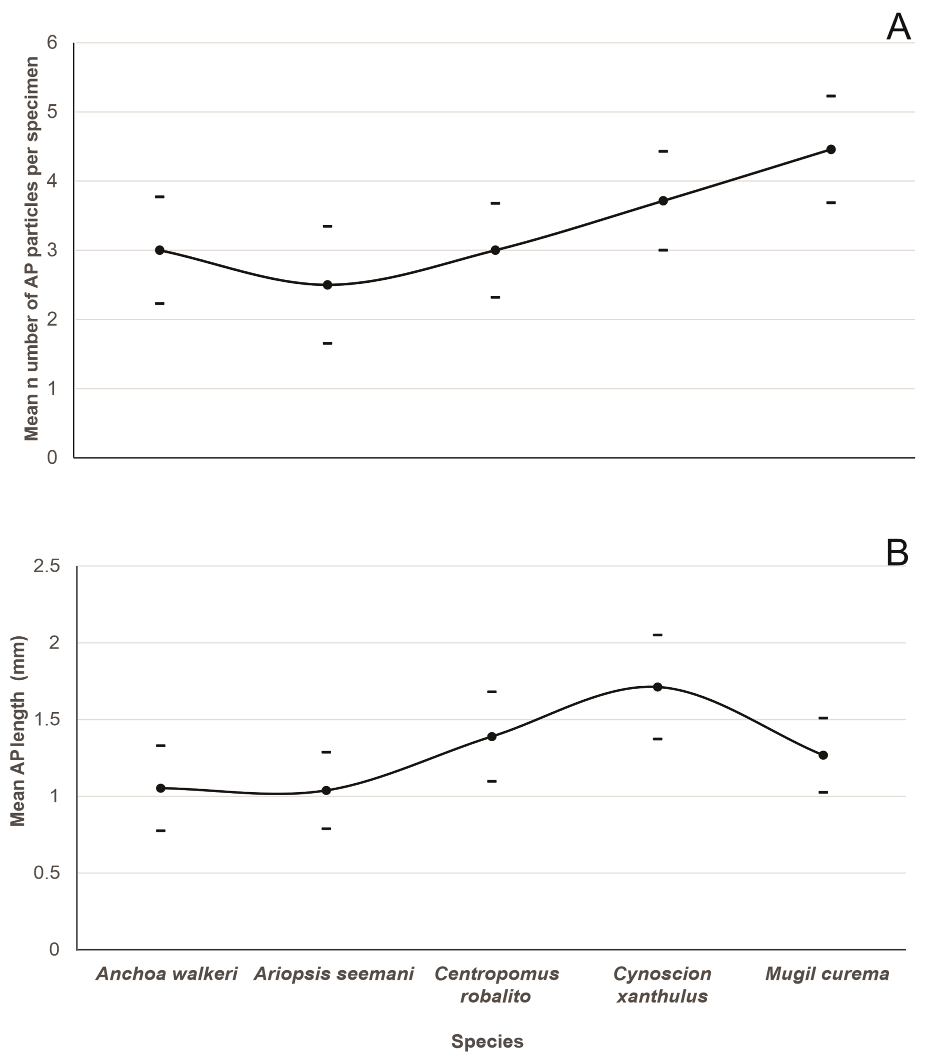

FIGURE 3
Results from the ANOVA showing the mean number of AP **(A)** and mean length (mm) **(B)** of the AP found in the gastrointestinal tracts of fish species analyzed.

3.3 FT-IR analysis

Results from the FTIR spectra show the presence of five types of APs in water and five in fish (Figure 4) (Table 2). In water, three polymers accounted for 94% of the particles found. Processed cotton was the most prevalent polymer with 615 particles (53%), all of which were fibers, followed by PET with 251 particles (22%), which were also fibers. Then it was followed by alkyd resin, which came in the shape of fragments, with 228 particles (20%). The remaining 6% was composed of cellulose fibers with 46 particles (4%), and finally fragments of diallyl phthalate resin, with 23 particles (2%).

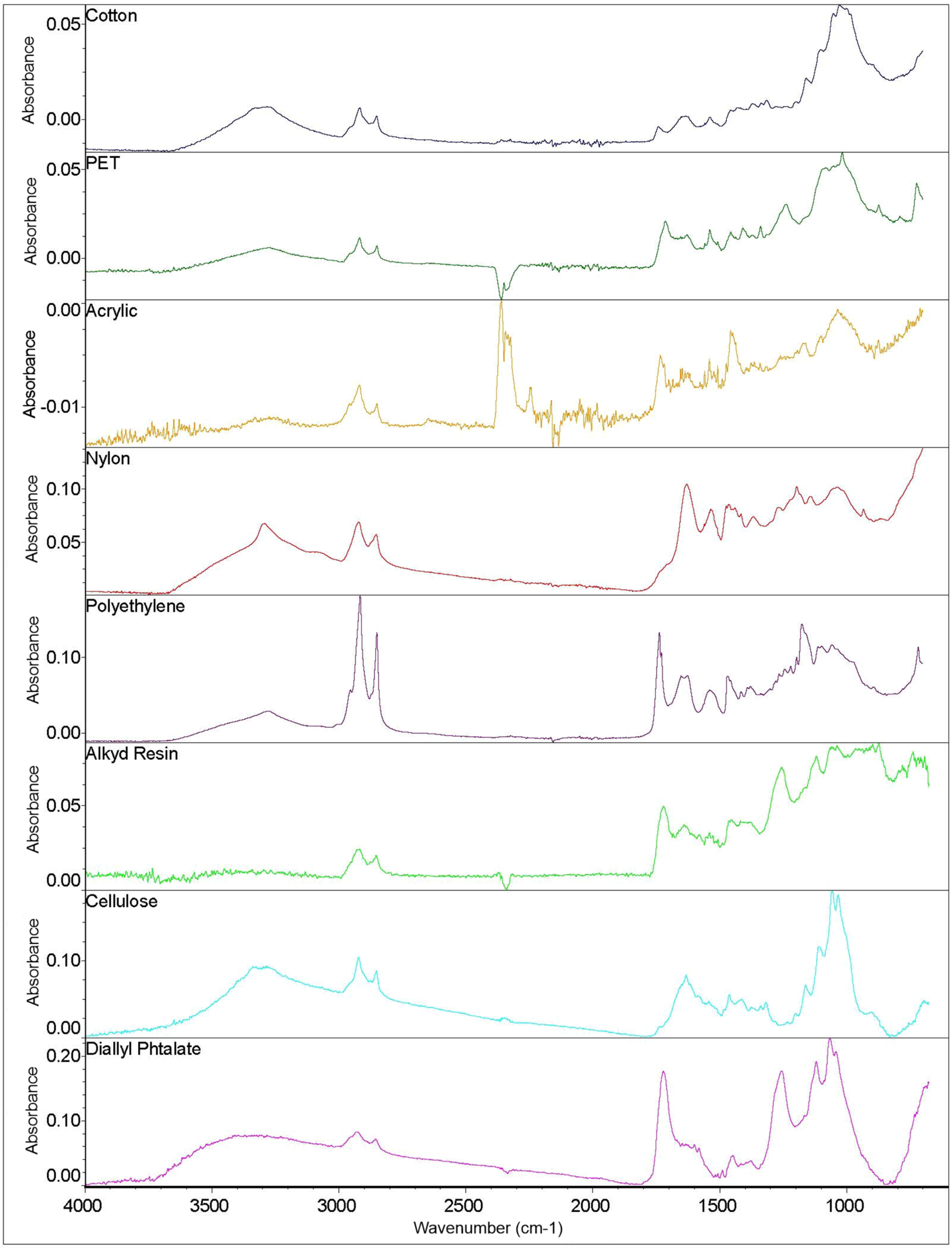

FIGURE 4
ATR-FTIR spectra of the AP found in water and the gastrointestinal tract of demersal fish from the Huizache-Caimanero estuairne system, in the northern TEP.

TABLE 2 Types (polymers) and numbers of the AP particles present in the water samples and gastrointestinal tracts of the demersal fish species analyzed.

		Cotton	Nylon	PET	Acrylic	Polyethylene	Alkyd resin	Cellulose	DAP	Total
Water		615	0	251	0	0	227	46	23	1162
Fish species	*Anchoa walkeri*	0	4	0	16	19	0	0	0	39
	Ariopsis seemanni	12	8	7	0	0	0	0	0	27
	Centropomus robalito	26	8	18	0	0	0	0	0	52
	Cynoscion xanthulus	24	7	16	7	3	0	0	0	57
	Mugil curema	21	23	5	4	7	0	0	0	60
Total Fish		83	50	46	27	29	0	0	0	235

In fish, three polymers were the most common types of plastics found, making up 76% of the total. Processed cotton was the most prevalent, with 83 particles (35%). Nylon was the second most common, with 50 particles (21%), and it was the only polymer found in all species. PET ranked third, with 46 particles (20%). The remaining two polymers accounted for 24% of the total, with polyethylene having 29 particles (12%) and acrylic being the least common with 27 particles (11%).

3.4 Multivariate analyses

PERMANOVA indicated that the diet of the analyzed organisms was significantly different according to the species, feeding guilds, and TP (Species pseudo-$F_{4,132}$ = 130.5, $p<0.05$; feeding guild pseudo-$F_{3,132}$ = 83.1, $p<0.05$; TP pseudo-$F_{2,132}$ = 107.4, $p<0.05$). These differences can be seen in the Principal Coordinates plot (Figure 5A), in which four clear-cut groups formed, each containing a feeding guild. Zoobenthivores and piscivores species, i.e., the snook and the weakfish, which are carnivores 2 and 3, are grouped. These results indicate that the selected species effectively have different eating habits and feeding guilds, and agree with the previous results presented for a neighborhood system (Muro-Torres et al., 2020).

When analyzing the presence of AP in the digestive tract of these species, PERMANOVA also indicated differences regarding the species, feeding guild, and TP (Species pseudo-$F_{4,126}$ = 29.1, $p<0.05$; feeding guild pseudo-$F_{3,126}$ = 34.2, $p<0.05$; TP pseudo-$F_{2,126}$ = 107.4, $p<0.05$). However, the PCO indicates only two groups (Figure 5B). One with the majority of the species in which the overlaid vector indicates the importance of the AP PET, processed cotton, and nylon to those species, and another group formed only by the anchovies, in which the most important APs were acrylic and polyethylene. Pairwise comparisons using a pseudo-t test confirmed that the ingestion of plastics differed in anchovies, a pelagic species, compared to all other species, and therefore AP ingestion also differed in planktivores of TP 1, concerning other feeding guilds and trophic position. In the case of demersal fish, which remain associated with the bottom, no differences were found among them for the ingestion of APs.

4 Discussion

This study reports the presence of AP in estuarine water and its correlation with fish ingestion across various trophic levels, feeding habits, and guilds in the TEP. This research is crucial due to the increasing human settlements near estuaries in tropical regions, leading to heightened AP waste in these environments (Collicutt et al., 2019).

The plastics found in the water samples are likely associated with the freshwater discharge from little channels running through agriculture fields, where plastic materials are employed (Alvarado-Zambrano et al., 2023; Wanner, 2021) as well as shrimp farms located on the southeastern margin of this lagoon (Figure 1). The Baluarte River, which flows through the northern part of the region and is fed by numerous agricultural irrigation canals, runs alongside the city of El Rosario before passing by several smaller towns on its way to the coast. The southern river, El Presidio, also flows through various human settlements before reaching the coast, although they are not as large as El Rosario. Urban areas are known to be potential sources of AP (Wagner et al., 2014). As a result, areas near population centers show a high influx of these particles, as our findings corroborate.

With respect to the APs found in fish, our results are consistent with previous results from a neighborhood estuarine system, in which similar values were found (Salazar-Pérez et al., 2021). This can be considered a high frequency of occurrence, which is expected in demersal estuarine species, as they have a high ingestion rate of APs; moreover, if it is considered that the estuarine environment is a significant accumulation zone for human waste (Zhang et al., 2019). As estuaries are a transitional ecosystem, often surrounded by urban areas and exposed to domestic sewage discharge, they receive contaminants from both riverine and tidal inputs (Lebreton et al.,

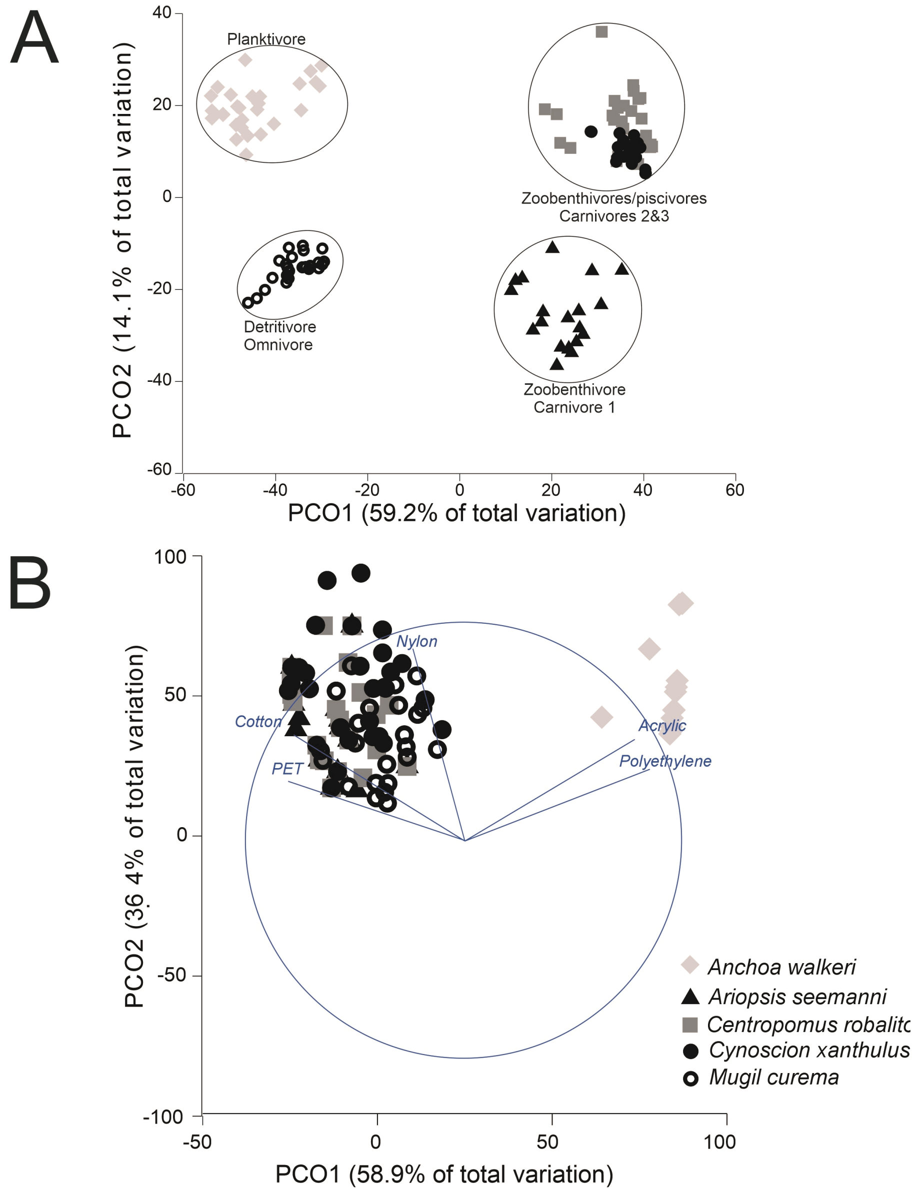

FIGURE 5
Principal coordinates analysis (PCO) describing the feeding behavior **(A)** and debris ingestion **(B)** of the analyzed fish species. The vectors indicate the importance of each prey item and polymer found in the gastrointestinal tract of this species.

2017), as well as from the fishing activities that usually occur in these ecosystems (Lima et al., 2014). Also, considering that both rivers influencing this system pass through several human settlements, as previously stated, the consumption of AP by fish is, therefore, higher close to urbanized areas (Silva-Cavalcanti et al., 2017).

Thereby, these ecosystems are more prone to be contaminated by APs (Bessa et al., 2018). Considering the activities surrounding the studied ecosystem, such as agriculture, shrimp farming, fishing, and the presence of human settlements (Valencia-Castañeda et al., 2022), it is expected that a high amount of these particles discarded into this estuarine system, ultimately end in the gastrointestinal tract of fish.

In terms of feeding habits and feeding guild, the results suggest that the white mullet, an omnivorous fish, had a higher concentration of APs in its digestive tract due to its diverse diet, which includes plants, algae, and invertebrates. While previous studies have highlighted that predator species are more susceptible to AP contamination through trophic transfer from contaminated prey (Ferreira et al., 2018), this was not the case in the current study. Instead, the omnivore/detritivore white mullet exhibited a higher mean abundance of APs, consistent with findings from similar studies in other regions (Wang et al., 2020), likely because omnivorous species have a higher potential for actively ingesting AP due to their foraging behavior across different resources and water depths (Mizraji et al., 2017). This may be favored because APs are widespread in aquatic environments, suspended in water because of turbulence, or deposited in sediment (Barnes et al., 2009).

The polymers identified with the FTIR analysis are associated with the activities developed in the studied area. Processed cotton is a polymer commonly used in the textile industry and discarded through laundry and is known for its persistence in the environment, contributing to pollution (Belzagui et al., 2020). In this case, we were able to distinguish processed cotton from other natural fibers because, in addition to the commercial libraries offered by the Nicolet system, we created a library containing the specific spectra of synthetic (anthropogenic) fibers of cellulose, rayon, and cotton (Supplementary Figure 1). For this reason, we can confirm that the cotton found is of anthropogenic origin. Considering that both rivers that arrive at this system pass through several human settlements, it is expected to encounter several discards of textiles.

PET is a polymer widely used in aquaculture systems and as single-use packaging in Mexico, leading to its abundance in the environment due to its slow degradation rate (Sekudewicz et al., 2021). In the region of our study, Nylon is frequently used in shrimp farming and fisheries for fishing nets and threads, making it a potential source of AP in the local environment (Páez-Osuna et al., 2023). Moreover, if it is considered that this system is under fishing pressure. Polyethylene is the most common polymer in the marine environment, as it is used in many everyday products, including containers (i.e., bottles, food, and detergent containers), bags (i.e., trash and grocery bags, agricultural mulch), packaging, ropes, toys among others (Andrady, 2017). Acrylic is widely used in fishing gear for various fisheries globally (Chumchuen et al., 2023) and in the region for manufacturing fishing rods used to catch tuna and other gamefish species. The presence of this polymer has also been reported in sediment and coastal waters (Neves et al., 2015). In the case of resins, alkyd resins are versatile materials commonly used in paints, varnishes, protective coatings, and various industries such as construction, automotive, and wood, commonly used for painting and varnishing marine equipment (Shtykova et al., 2006), whilst the diallyl phthalate is a commonly used material in the boating industry due to its inert and moisture-resistant properties. However, its monomer form is considered an aquatic hazard and has already been reported on aquatic organisms (Ciocan et al., 2020).

As previously mentioned, the presence of these polymers aligns with the activities conducted in the study area. The prevalence of fibers in the gastrointestinal tracts of fish also corresponds with previous findings of AP in shrimp within the same ecosystem (Valencia-Castañeda et al., 2022), where fibers were also the predominant form. The two most common polymers detected in the water samples, cotton and PET, were among the most abundant polymers found in the gastrointestinal tracts of the fish species analyzed, indicating a correlation between what is present in the water column and what is ingested by fish. It is important to note that while fragments were the main form of microplastics in the water, fibers were the primary form found in fish, suggesting that fish and shrimp primarily ingest fibers, possibly mistaking them for prey. Additionally, the water samples provide a snapshot of the current plastic content, whereas the plastic content in fish gastrointestinal tracts reflects continuous feeding habits in the area. Therefore, fish serve as effective indicators of the AP found in the systems they inhabit. Furthermore, fish can migrate between systems, leading to the presence of plastics like nylon, polyethylene, and acrylic in species known for high migration patterns such as anchovies and mullets (Amezcua and Amezcua-Linares, 2014; Avigliano et al., 2021), indicating that some of the observed plastics may have originated from other ecosystems.

The multivariate analyses indicate that TP, feeding habits, and different trophic guilds do not influence AP consumption, contradicting our initial hypothesis, but rather, it appears that the position in the water column influences this behavior. It is known that polyethylene is a polymer that floats in seawater, even with additives and fillers, sharing the photic zone with phytoplankton, exponentially decreasing in concentration from the surface to about 5m (Kooi et al., 2016). Therefore, planktonic fishes feeding in the euphotic zone are documented to ingest floating microplastics (Neves et al., 2015), such as polyethylene and, in this case, also acrylic. As such, the type of AP ingestion and their intensity seem to be related to their habitat, i.e., where in the water column they are feeding, as well as their feeding strategies. However, it is necessary to consider that most AP found in aquatic environments likely start on the surface, but even buoyant AP eventually sink and become tangled with other debris or consumed by marine life, ultimately settling in the seafloor sediment, as such, the consumption of typically floating AP debris can be also found in demersal fish or benthic feeders.

The presence of AP in this system is linked to strong connections between aquatic and terrestrial environments (McNeish et al., 2018), with point sources such as urban rivers draining into the systems, fishing nets, discarded products, atmospheric deposition, and stormwater runoff contributing to the pollution (Claessens et al., 2013). Agricultural fields, which are common in the area (McNeish et al., 2018), and washing machine effluents (Browne et al., 2007; Salazar-Pérez et al., 2021b), which are discharged to the rivers passing through the urban settlements, are significant non-point sources of AP pollution, with washing machine effluents being a major contributor to fiber release, which are the most prevalent types of microplastic in fishes, and in the studied area, also shrimps (Campbell et al., 2017; Malthaner et al., 2024; Pinho et al., 2022; Salazar-Pérez et al., 2021; Valencia-Castañeda et al., 2022). Several studies have found that fish consume high amounts of fiber compared to other types like fragments and films (Bessa et al., 2018; Silva-Cavalcanti et al., 2017), therefore, even if in the surrounding water, the main AP are fragments, fish would eat fibers instead, probably because these are easily mistaken by prey.

Finally, the differences in AP ingestion among fish species appear to be linked to their position in the water column rather than their feeding habits. The presence of specific types of AP in the water and fish stomachs is a reflection of the local human activities.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: http://uninmar.icmyl.unam.mx/.

Ethics statement

Ethical approval was not required for the study involving animals in accordance with the local legislation and institutional requirements because the animals used (fishes) were commercially captured by local fishers with the proper fishing permits issued by the Mexican government.

Author contributions

CG-R: Formal analysis, Writing – original draft, Visualization, Resources, Funding acquisition, Supervision, Methodology, Writing – review & editing, Investigation. FA: Funding acquisition, Validation, Writing – review & editing, Project administration, Formal analysis, Conceptualization, Resources, Supervision, Writing – original draft, Data curation, Methodology, Investigation, Visualization, Software. RC-G: Methodology, Investigation, Writing – review & editing, Formal analysis, Data curation. JR-H: Writing – review & editing, Methodology, Investigation, Visualization, Validation. VM-T: Investigation, Validation, Writing – review & editing, Formal analysis, Data curation, Writing – original draft, Methodology, Visualization.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2025.1615827/full#supplementary-material

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