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Prevalence of microplastics in Peruvian mangrove sediments and edible mangrove species

Angelica Aguirre-Sanchez [a,*], Sara Purca [b], Matthew Cole [c], Aldo G. Indacochea [a], Penelope K. Lindeque [c]

[a] *Facultad de Ciencias Veterinarias y Biológicas, Biología Marina, Laboratorio de Ecología Marina, Universidad Científica del Sur, Lima, Peru*
[b] *Área Funcional de Investigaciones Marino Costeras (AFIMC), Dirección General de Investigaciones en Acuicultura (DGIA), Instituto del Mar del Peru (IMARPE), Callao, Peru*
[c] *Marine Ecology & Biodiversity, Plymouth Marine Laboratory, Plymouth PL1 3DH, United Kingdom*

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ABSTRACT

Mangrove ecosystems have been hypothesised as a potential sink of microplastic debris, which could pose a threat to mangrove biota and ecological function. In this field-study we establish the prevalence of microplastics in sediments and commercially-exploited *Anadara tuberculosa* (black ark) and *Ucides occidentalis* (mangrove crab) from five different zones in the mangrove ecosystem of Tumbes, Peru. Microplastic were evident in all samples, with an average of 726 ± 396 microplastics/kg for the sediment, although no differences between the different zones of the mangrove ecosystem were observed. Microplastic concentrations were 1.6± 1.1 items/g for the black ark and 1.9 ± 0.9 microplastics/g for the mangrove crab, with a difference in the microplastic abundance between species ($p < 0.05$), and between the gills and stomachs of the crab ($p < 0.01$). Human intake of microplastics from these species, for the population in Tumbes, is estimated at 431 items per capita per year. The outcomes of this work highlight that the mangrove ecosystem is widely contaminated with microplastics, presenting a concern for the marine food web and food security.

1. Introduction

Marine plastic is a global pollutant that can have negative impacts on ecosystems, ecosystem services, the economy and society (Clark et al., 2016; Iroegbu et al., 2021; Napper and Thompson, 2019). Of widespread environmental concern are microplastics, describing small plastic particles (0.1 um - 5 mm diameter) that are either intentionally manufactured to be microscopic in size, or derive from physical, chemical and biological fragmentation of macroplastics (Cole et al., 2011; John et al., 2022; Maghsodian et al.,2022). Given their small size, microplastics can be consumed by an array of marine biota, exposing them to plastic-associated chemical compounds such as UV stabilizers, pigments, antioxidants, plasticizers and flame retardants (Crawford and Quinn, 2017; Hamilton et al., 2022; Kühn et al., 2020). There is widespread evidence that microplastics can cause adverse health effects in exposed organisms (Doyle et al., 2022).

Coastal mangroves are “blue carbon” ecosystems valued for their high productivity, biodiversity and their role in carbon sequestration (Alongi, 2020; Hilmi et al., 2021; Rovai et al., 2022; Taillardat et al., 2018). However, the ecosystem services provided by mangroves are at risk from anthropogenic activities and pollution, such as plastic (Deng et al., 2021). Field studies have demonstrated that macroplastic debris can become entrapped in aerial roots or the interior scrub zone of the mangrove (Garcés Ordóñez et al., 2019; Meera et al., 2022). Further, there is some indication that microplastics can accumulate in underlying sediments and be ingested by or adhere to the gills or appendages of a wide range of aquatic organisms, including commercially exploited invertebrate species (Cordova et al., 2021; Maghsodian et al., 2022; Meera et al., 2022).

In Peru, the Tumbes mangroves span 5974 ha from the Ecuadorian border (International Channel) to Playa Hermosa (Tumbes) providing refuge to an array of commercially exploited species (INRENA, 2007). In the Rural and Tourist Central Zone, mangroves have been removed to allow for shrimp farms and rural urbanisation, with beaches and tourism in the crocodile (*Crocodylus acutus*) vivarium being major anthropogenic influences of plastic (INRENA, 2007). The mouth of Tumbes river is located in the Lower Zone, (Fig. 1); here the river water is highly contaminated by heavy metals such as lead, exceeding water quality

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* Corresponding author.
E-mail address: 100019299@cientifica.edu.pe (A. Aguirre-Sanchez).

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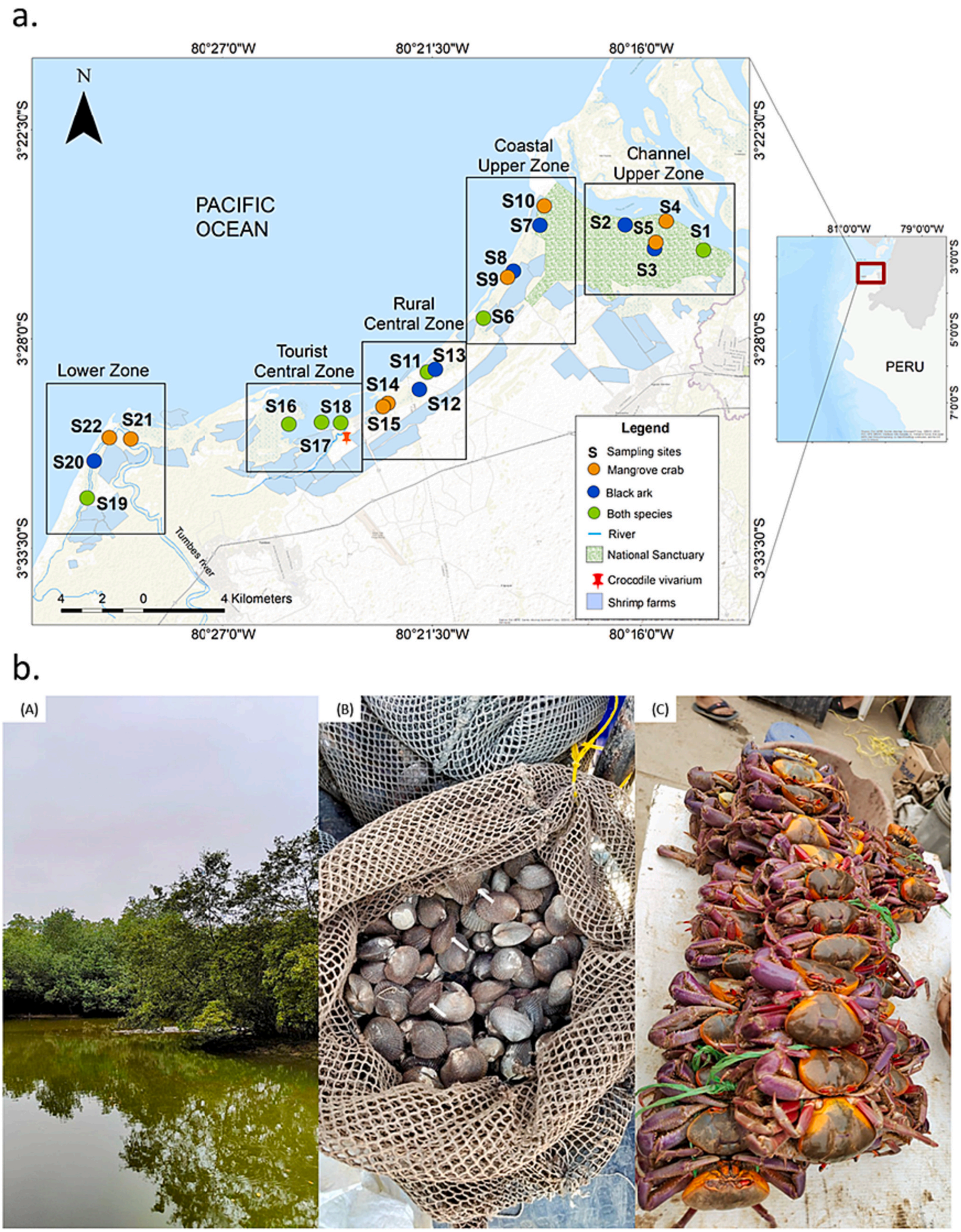

Fig. 1. a. Location of field sampling sites for the collection of sediments, mangrove crab (*Ucides occidentalis*) and black ark (*Anadara tuberculosa*). b. (A) The Tumbes mangrove ecosystem and their principal commercial species: (B) the black ark (*Anadara tuberculosa*) and (C) the mangrove crab (*Ucides occidentalis*).

standards (from 0.05 mg/L to 0.3174 mg/L), adversely affecting the inhabitants and the native fauna in this area (Gavilanez Garcia, 2016). Anthropogenic activities (e.g. aquaculture, tourism) can adversely impact on the mangroves (Dioses Puelles, 2020). As such, inside the Channel Upper Zone and Coastal Upper Zone (Fig. 1), the National Sanctuary Los Manglares (SNLMT) was created, under the RAMSAR Convention on Wetlands of International Importance Especially as Waterfowl Habitat 1997 (Angulo, 2014; INRENA, 2007; Martínez, 2021).

The edible invertebrates *Anadara tuberculosa* (black ark) and *Ucides occidentalis* (mangrove crab) are of highest commercial value in Tumbes mangroves and support the nutrition and socio-economic wellbeing of inhabitants in the region (INRENA, 2007). *A. tuberculosa* are filter-feeding bivalve shellfish with distinctive dark hairy periostracum that live buried at a depth of 1–20 cm in muddy-silty sediments in the low intertidal zone associated with the red mangrove *Rhizophora mangle* (Lazarich Gener et al., 2008) (INRENA, 2007) (Fig. 1b.B). *U. occidentalis* is a detritivorous crab that feed on *R. mangle* leaves and organic matter in the mangrove sediment, which burrow in muddy-silty sediments below red mangrove roots in the high intertidal zone (Alemán and Ordinola, 2017; Cabanillas et al., 2016; Ordinola et al., 2010; Zambrano and Meiners, 2018) (Fig. 1b.C). The black ark and mangrove crabs are manually extracted by fishermen, commonly called “concheros” and “cangrejeros”, in a sustainable manner which is recognised as part of the ‘Cultural Heritage of the Nation’ in Peru since 2022 (N° 000036-2022-VMPCIC/MC) (Ordinola et al., 2019; Martínez, 2021). These mangrove species are typically eaten whole (i.e. gills, digestive tract is consumed) in traditional dishes such as black ark ceviche, crab carapace, crab chupe and Tumbesian majarisco (Martínez, 2021). Aguirre-Sanchez et al. (2022) evidenced the presence of microplastics in the gills and digestive tract of 30 mangrove crabs collected from local markets in the city of Tumbes, noting this may pose a risk to food security (Caruso, 2019). For this reason, the primary objective of this field-study is to establish the prevalence of microplastics in sediments and commercially-exploited *A. tuberculosa* and *U. occidentalis* of the mangrove ecosystem of Tumbes, Peru, and estimate dietary exposure to microplastics in local populations.

2. Materials and methods

2.1. Sampling design

In November 2021, mangrove crabs (*U. occidentalis*), black arks (*A. tuberculosa*), and mangrove sediment were collected from 22 sampling sites located throughout the mangrove ecosystem of Tumbes (Fig. 1; S3). The sampling sites were located within five different geographical zones: 1) The Channel Upper Zone, located in the National Sanctuary and close to the International Channel between Peru and Ecuador; 2) the Coastal Upper Zone, located between the shore and the National Sanctuary with shrimp farms in the area; 3) the Rural Central Zone, located in an area with only shrimp farms in it; 4) the Tourist Central Zone, located in Puerto Pizarro bay near the crocodile vivarium being the most touristic zone in the Peruvian mangrove ecosystem; and 5) the Lower Zone which is located in the mouth of Tumbes river.

Invertebrates were collected using the Cultural Heritage of the Nation technique (Peruvian article No. 000036-2022-VMPCIC/MIC). At each site 3 specimens of each species were collected between the tidal channel and mangrove canopy. Mangrove crabs (45 individuals across 15 sites) and black arks (42 individuals across 14 sites) were stored in a cooler covered with aluminium foil, and transported to the IMARPE coastal laboratory for further processing.

Discrete sediment samples (750 cm^3) were collected from the top 5 cm of intertidal sediment between the shore and canopy ($n = 22$) using a stainless-steel shovel. Sediment samples were stored in a handmade aluminium box (R. Li et al., 2020), and transported to the IMARPE coastal laboratory where the pH of the samples was evaluated using a portable potentiometer (HI99121/Hanna) at a controlled temperature (22 °C). The average pH of the sediment from every zone was 6.5 ± 0.6. Sediments were stored at 0 °C until further treatment.

2.2. Digestion of the soft tissue and isolation of microplastics for the mangrove crab (Ucides occidentalis) and the black ark (Anadara tuberculosa)

In the laboratory, soft tissues were excised using stainless-steel tweezers, scissors and scalpel and their wet-weight recorded (Ohaus Adventurer AR3130 analytical balance). The gills and stomachs of the mangrove crabs and the soft tissue of the black arks were individually wrapped in aluminium foil and stored at 0 °C prior to microplastic extraction (Naji et al., 2018). Potassium hydroxide (KOH) is a strong base that can effectively remove biological material without damaging microplastics (Dehaut et al., 2016; Kühn et al., 2017; Lusher et al., 2017). In this study, soft tissues were placed in 50 mL Falcon tubes with 50 mL of 10 % KOH, maintained in an incubator (INCUCELL 111/MMM Medicenter) at 60° for 48 h, intermittently manually shaking the tubes to facilitate digestion (Aguirre-Sanchez et al., 2022). Subsequently, the supernatant was filtered through a 45 μm nylon mesh filter (47 mm diameter). Owing to the muddy habitat in which the invertebrates live, sediment was found in all samples. Therefore, digests underwent density-separation, whereby digests were rinsed back into their original Falcon tube with 25 mL of 1.2 g/mL sodium chloride (NaCl), shaken manually and then left to rest for 20 min. Finally, the supernatant was filtered through a nylon mesh filter with 45 μm The filter was immediately placed in a labelled Petri dish and sealed with Parafilm (Coppock et al., 2017).

2.3. Processing the matrix: Sediment

To separate microplastic from mangrove sediment, a multi-step protocol was applied. First, sediment samples were dried at 50 °C for 72 h (Coppock et al., 2017), due to the presence of clay and silt in the sediment, it had to be manually ground using a mortar and pestle to homogenise the sample. Next, 40 g of dry sediment was digested in 50 mL of 20 % KOH at 60′C for 48 h. Then the supernatant was filtered through a 45 m nylon mesh filter. Per the density-separation protocol of Coppock et al. (2017), the digested sediment was added to a Sediment-Microplastic Isolation (SMI) unit with 700 mL of brine. For this study, the brine was hypersaline NaCl solution (1.2 g/cm3), which is both cost-effective and environmentally benign, with the capacity to float-out commonly used polymers including polypropylene, polyethylene and polystyrene. Following density-separation, the upper layer of the brine was filtered sequentially through 300 μm and 45 μm nylon mesh filters, and filters then stored in a Petri dish sealed with Parafilm.

2.4. Visual identification

A stereomicroscope (Olympus SZX16) was used to visualise putative microplastics on each mesh filter. Putative microplastics were identified based on their shape, colour and size. For each particle, their shape, size and optical properties (colour) was recorded (Lusher et al., 2020). Particle shape were classified as foam, film, fibre, pellet, microbead and fragment (Kovač Viršek et al., 2016). Particle size (longest dimension) was measured using CellSens(R) (Olympus). Given weather and KOH digestions can result in colour leaching (Bråte et al., 2018), particle colours were categorised broadly (e.g pink, violet, lilac as red) (Lusher et al., 2020).

2.5. FT-IR analysis

Following morphological and optical classification, a randomly selected subsample ($N = 213$) of the putative particles were selected for polymeric analysis. Per Cole et al. (2023), putative microplastics were placed on pre-labelled divots on aluminium-coated slides, and analysed using Fourtier-transform infrared (FT-IR) spectroscopy (Spotlight 400, PerkinElmer) at Plymouth Marine Laboratory (UK). Scans were performed in reflectance mode (4000–600 cm-^{1}; 10 scans). Resultant spectra were compared with in-house and commerically-available polymer libraries with matches of ≥65 % considered acceptable (Fu et al., 2021). Owing to the challenges of differentiating natural and anthropogenic cellulose, particles with spectra matches to cellulosic materials were considered plastic if their colour was red or blue. The percentage of putative microplastics confirmed to be anthropogenic polymers was 60 %, and this value was used as a conversion rate to calculate microplastic concentrations based on the number of putative microplastics identified in each sample.

2.6. Quality assurance (QA) and quality control (QC)

Microplastics contamination can stem from airborne deposition, clothing and consumer products (Henry et al., 2019; Jarosz et al., 2022; van Wezel et al., 2016). To minimise potential contamination of samples, and account for any contamination that may occur during sampling and processing a number of steps were taken to limit contamination during sampling, use of protective equipment made of cotton was encouraged. In the laboratory and field, the majority of apparatus and storage vessels were replaced with glass or metal, and samples covered with aluminium foil (Prata et al., 2021). To prevent airborne contamination, all laboratory equipment was washed, rinsed with 70 % alcohol and stored in a laminar flow hood, and rinsed three times with filtered distilled water before used and between the samples (Li et al., 2022; Prata et al., 2021). All solutions (e.g. KOH, NaCl) were filtered through a 0.5 um glass fibre filter and stored in clean glass bottles prior to use (Prata et al., 2021). Lastly, procedural blanks and open filters (comprising 45 μm nylon mesh filter) were used to account for contamination. Analysis of blanks showed an average of 2±2 microplastics per sample, with a detection limit of the method of the minimum size of plastic that can be detected is 1.1 *μm*,and this metric was used to adjust microplastics concentrations in samples accordingly.

2.7. Human exposure to microplastics assessed by shellfish consumption in Tumbes

The annual intake of mangrove crab and black ark per capita in Tumbes region was obtained using the following formula (Eq. (1)), with a regional population of 179,900 inhabitants aged 10 years (INEI, 2018) and an annual extraction for direct human consumption of 31.4 tons for mangrove crab and 12.7 tons for black ark (Ordinola Zapata, 2022). Subsequently, the average number of microplastics in soft tissue was used to estimate the approximation of human intake of microplastics from *U. occidentalis* and *A. tuberculosa* (Eq. (2)).

$$Intake\ of\ shellfish\ per\ year\ per\ capita\ (g/inhabitant) = \frac{annual\ production\ of\ shellfish\ (g)}{number\ of\ inhabitant\ in\ the\ region\ (inhabitants)} \tag{1}$$

$$Micropastic\ intake\ by\ human\ per\ year\ per\ capita\ (MP\ items/year/capita) = average\ of\ MP\ items\ in\ the\ soft\ tissue\ of\ the\ organism\ (MP\ items/g)\ x\ intake\ of\ shellfish\ per\ year\ per\ capita\ (g) \tag{2}$$

2.8. Statistics

The normal distribution of the data and the homogeneity of variances were verified using Shapiro-Wilk and Levene's test. Non- parametric data was transformed using log. The non-parametric data of the microplastic concentration between species and tissues in the mangrove crab was compared using Mann-Whitney-Wilcoxon test. Two-way ANOVA and post hoc Tukey test was used to compare the average number of microplastics per species among the different zones of the Tumbes mangrove and one-way ANOVA and Kruskal-Wallis tests were used to compare microplastic abundance in the sediment, black ark and mangrove crab among the zones. The Pearson correlation analysis was used to calculate the correlations between variables. Statistics were executed in RStudio program (R Core Team, 2020).

3. Results

3.1. Microplastic abundance in the mangrove crab and the black ark

In the black ark, microplastic concentrations were 1.56 ±1.12 items/g (4.9±2.18 items/ind). In the mangrove crab, microplastic concentrations were 1.94 ± 0.87 items/g (7.8 ± 3.14 items/ind). Across all sites the mangrove crabs showed significantly greater microplastic concentrations in their gills and stomach than observed in the soft tissues of the black ark (Mann-Whitney-Wilcoxon, *p*-value = 0.02; Fig. 2A). Microplastic averages differ significantly between species (two-way ANOVA, p-value = 0.01; Tukey post hoc, *p*-value = 0.01) but not between zones (p-value = 0.19) or in the interaction between species and zones (*p*-value = 0.3362). Microplastic concentrations in the crab gills were 4.1 ± 2.41 items/g, which is significantly greater than the 0.8 ± 0.7 items/g

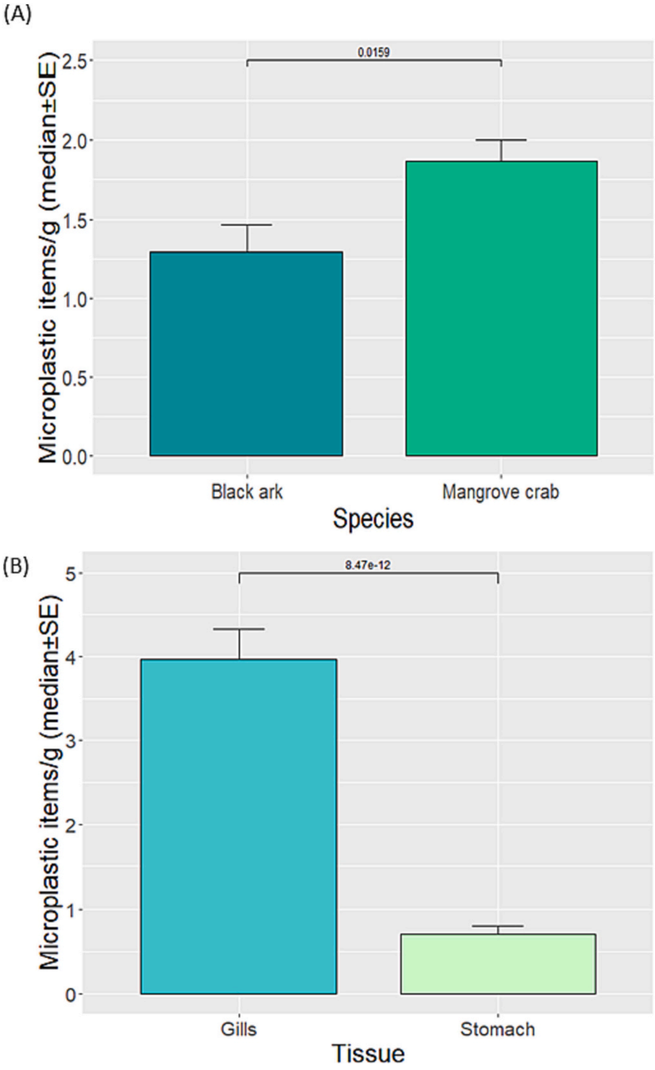

Fig. 2. (A) Microplastic abundance (items/g) between the mangrove crab and the black ark differ significantly (Mann-Whitney-Wilcoxon, p-value = 0.02). (B) Microplastic abundance between the tissues of the mangrove crab differ significantly (Mann-Whitney-Wilcoxon, p-value = 8.47e^{-}12).

observed in the crab stomach (Mann-Whitney-Wilcoxon test, *p*-value = 8.47e^{-}12, S1, S2, Fig. 2B). No significant difference was evident between the abundance of microplastic particles (items/g) for the black ark among different zones of the Tumbes mangrove ecosystem (Kruskal-Wallis, p-value = 0.18)(Fig. 3A) or for the mangrove crab among different zones (Kruskal-Wallis, p-value = 0.97) (Fig. 3B).

3.2. *Microplastic abundance in mangrove sediments*

Microplastics were identified in all sediment samples tested with concentrations ranging 480 ± 342.5 to 870 ± 591.9 items/kg. No significant differences between the abundance of microplastic particles (items/kg) was evident among different zones of the Tumbes mangrove ecosystem (one-way ANOVA, p-value =1.02) (Fig. 3C).

3.3. *Relationship between microplastics in the sediments and in the invertebrates*

No significant linear relationship were detected between the abundances of microplastics in the sediment and in the mangrove crab (Pearson: R = -0.02; p-value >0.05) and in the black ark (Pearson: *R* = 0.03; p-value>0.05). The abundances of microplastics in the in the black ark also demonstrate no significant relationship with the abundances in the mangrove crab (Pearson: *R* = 0.07;p-value >0.05).

3.4. *Putative microplastic characteristics*

Putative microplastics comprised microbeads, fragments, fibres and films (Fig. 4a). Fibres and films were the most common categories of microplastics in the black ark (80.6 %, 11.1 %), mangrove crab (82.3 %, 6.6 %) and sediment (33 %, 63 %) (Fig. 4b).

The particle sizes were binned into four size classes: 1–249 m, 250–499 m, 500–999 m and 1000–5000 m. Putative microplastics in the size class of 1–250 m were most prevalent in the black ark (36.6 %), mangrove crab (30.9 %) and sediment (85.6 %). Larger microplastics (>500 m) were the least prevalent size classes in biota and sediments (Fig. 4c).

Putative microplastics in both invertebrates and the sediment were predominantly transparent (black ark: 45.7 %, mangrove crab: 55.7 %, sediment: 22.7 %), blue (black ark: 32 %, mangrove crab:27.1 %, sediment:8.1 %) and red (black ark: 12.6 %, mangrove crab:8.5 %, and sediment:10.9 %) (Fig. 4d).

The polymers found in the subsamples were Cellophane, Polyethylene (PE), Polyester (PL), Polyvinyl chloride (PVC), Polystyrene (PS), Polyacrylamide (PAM), Polypropylene (PP), Enzacryl polyacetal, Phenol resin, Nylon (NY-Poly caprolactam), Polyacrylic acid (PAA) and Polyacrylonitrile (PAN) (Fig. 5).

3.5. *Estimated intake of microplastics by Tumbes inhabitants*

The ingestion of microplastics by local inhabitants from consuming black ark and mangrove crab was estimated as 431 microplastics/capita/year (Table 1).

4. Discussion

4.1. *Sediment*

This study provides the first data relating to microplastics in Peruvian mangrove ecosystems, with microplastic concentrations of 726±395.9 items/kg sediment. In Peru, few studies have addressed the presence of microplastics in coastal sediments (Canchari Madueño and Iannacone, 2022; Dávila and Vasquez, 2021; De-la-Torre et al., 2020; Iannacone et al., 2020; Losno Prado, 2020; Manrique Muñante, 2019; Purca and Henostroza, 2017; Contreras et al., 2022; Zárate and Iannacone, 2021). On sandy beaches, the highest abundance of microplastics per square meter was found in the Lima region (between 43 and 522 items m^{2}) (Purca and Henostroza, 2017, 2017; Contreras et al., 2022; De-la-Torre et al., 2020), and the highest abundance of microplastics per kilogram of sediment was found in Carpayo beach with 202.02 ± 10.28 particles/kg (Zárate and Iannacone, 2021). Elsewhere, Canchari Madueño and Iannacone (2022) found microplastic concentrations of 567 microplastics/kg in the irrigation channel of Yuncaypara, Manrique Muñante (2019) identified 90 items/kg from the sediments located in the mouth of the river Jequetepeque, and Losno Prado (2020) found 64 items/kg in Los Pantanos de Villa wetland mud. As such, the concentrations found in the mangroves is higher than observed elsewhere in Peru, suggesting the mangroves are accumulating microplastics. Mangrove roots and pneumatophores promote sedimentation of suspended particles without resuspension (Cozzolino et al., 2020), and we hypothesise this effectively supports the deposition and degradation of plastic particles in the sediment (Komiyama et al., 2008; Maghsodian et al., 2022; Martin et al., 2019).

The microplastic abundance in this study (726±395.9 items/kg) was below those reported in mangrove sediments collected from Indonesia - 2358 items/kg (Hastuti et al., 2019), Malaysia - 3500 items/kg and 4000 ± 29.174 items/kg (Hamid et al., 2020; Tan and Mohd Zanuri, 2023), China with the highest abundance of 7900 items·kg^{1} (Zuo et al., 2020), Colombia with a maximum concentration of 2745 ± 1978 items/kg (Garcés Ordóñez et al., 2019) and Brazil with 10,782 ± 7671 items/ kg (da Paes et al., 2022). However, our microplastics concentrations were greater than reported for mangrove ecosystems in Iran (34.5 items/kg) (Naji et al., 2019) and Singapore (62.7 ± 27.2 items/kg) (Mohamed Nor and Obbard, 2014). Differences in microplastic concentrations may stem from differing levels of human activities in the study area, riverine catchment and connected via oceanic currents, the ubiquity of plastics used in the local area, as well as the methods used to isolate and identify microplastics. Sampling within mangroves is challenging owing to the protected status of such ecosystems, difficulties in accessing sampling sites and the complexity of isolating microplastics from fine sediments (Garcés Ordóñez et al., 2019; Duan et al., 2021; Maghsodian et al., 2022).

Within this study, there was no significant difference in microplastic concentration between the different zones of the Tumbes mangrove ecosystem (Fig. 4C). This is likely due to a high degree of anthropogenic pressure throughout the entire mangrove. The inadequate management of plastic in the National Sanctuary has previously been evidenced during the cleaning of the mangrove carried out by Conservación Internacional Peru (2023), where plastic bottles and bottle caps were widely evident. The upper zone is prone to waste stemming from the international channel between Peru and Ecuador, where the currents can carry litter dumped from both sides of the border (Montaluisa Balcázar and Sánchez Cuenca, 2021). In the Coastal Upper and Rural Central Zones shrimp aquaculture has resulted in the introduction of fishing nets, foam buoys, paddlewheels and nursery cages into the area (Lusher et al., 2017). Such plastic equipment can become abraded and fragmented via chemical, physical and biological processes, leading to the release of secondary microplastics into the mangrove ecosystem (Lin et al., 2022). The Tourist Central Zone, which had the highest microplastic concentration of 933±364 items/kg hosts busy shipping ports and tourist hotels and beaches (Morán and Hidalgo, 2018). Previous studies have demonstrated that the bay of Puerto Pizarro in the Tourist Central Zone is polluted with other marine contaminants, with organophosphate levels in the sediment and water exceeding the Maximum Permissible Limits (Moran Avila, 2017). Similarly, in the Lower Zone overuse of insecticides, pesticides, and herbicides on plantain and rice farms in the river catchment have led to heightened metal and chemical concentrations in the Tumbes estuary (Tineo Nuñez and Periche Viera, 2019).

The presence and abundance of microplastics in the sediments can influence the levels of pH in the mangrove soil, increasing it

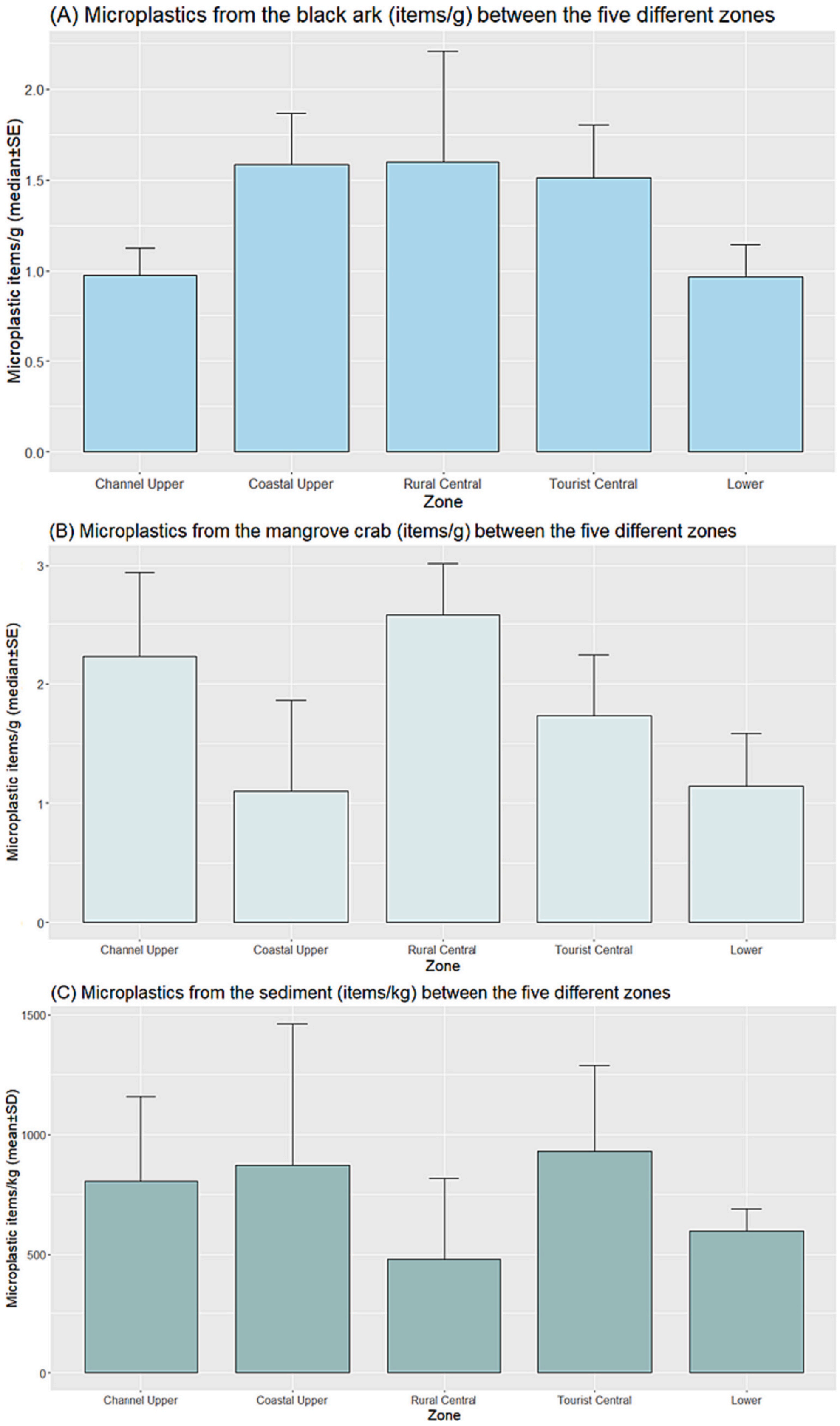

Fig. 3. (A) Microplastic median items/g (median ±SE) from the black ark among the zones did not differ significantly (Kruskal-Wallis, p-value = 0.18). (B) Microplastic median items/g (median ± SE) from the mangrove crab did not differ significantly between zones (Kruskal-Wallis, p-value = 0.97) (C) Microplastic average items/kg (mean ± SD) from the sediments among the zones did not differ significantly between zones (one-way ANOVA, p-value = 1.02).

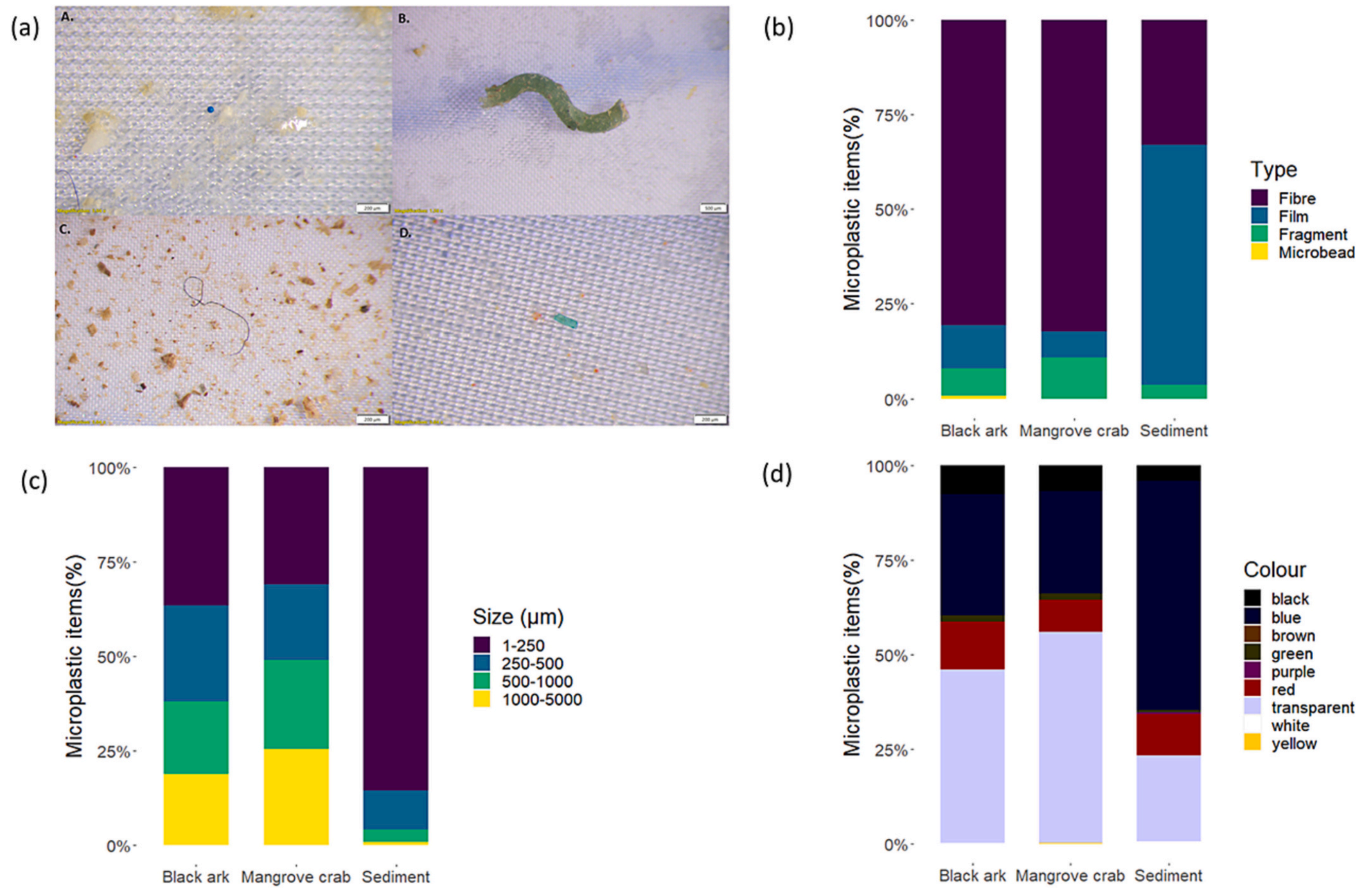

Fig. 4. (a) Putative microplastic type according to their shape: A. blue microbead, B. green fragment, C. blue fibre and D. green film. Proportion of microplastic according to their (b) shape, (c)size and (d)colour. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(Maghsodian et al., 2022; Zhao et al., 2021). Polyethylene foams and films had a direct effect on increasing soil pH (Zhao et al., 2021). However, the presence of plants in the mangrove soil potentially mitigates the effects of microplastics on soil pH, this attributed to the increase in aeration and porosity of the substrate when these polymers were adhered; likewise, the leaching of the additives that the microplastic presents alters the microbiota and therefore an increase in pH occurs (Lozano et al., 2021; Zhao et al., 2021). Despite obtaining a total of 716 ± 395.9 items/kg, the pH was 6.54 ± 0.57 due to the presence of *R. mangle* roots in the sampling areas. This was also observed in the results of Maghsodian et al. (2021), where pH was inversely proportional to microplastic abundance, with higher particle abundance when the pH was 6.86 compared to when it was 10.

4.2. Mangrove and estuary crabs

The pathways for microplastic uptake in crustaceans are the ventilation system (gills) and ingestion (stomach) (Daniel et al., 2021). In the present study there was a significant difference between the microplastic abundance found in both tissues with a mean of 4.1 ± 2.41 items/g for the gills and 0.8 ± 0.7 items/g for the stomach. The higher concentrations on the gills may be a result of prolonged retention times as compared with the intestinal tract (D'Costa, 2022; Villegas et al., 2021). In laboratory studies, the crab *Uca rapax* retained polystyrene fragments on their gills for two months (Brennecke et al., 2015), and the crab *Carcinus maenas* retained polystyrene microspheres microplastics on their gills for 21 days (Watts et al., 2014).

Feeding studies with crabs indicate microplastic abundance may be related to the feeding behaviour of the organism (D'Costa, 2022; Not et al., 2020; Villegas et al., 2021; Zhang et al., 2023). Among the commercial mangrove and estuary crabs, the omnivorous *Metopograpsus quadridentatus* has been reported with the highest microplastic abundance (33 items/g - 327.56 items/ind) (Mufti et al., 2020), while the herbivorous crab *Chiromantes dehaani* consumed the least amount of microplastic (0.74–4.96 items/ind) (Zhang et al., 2021). In Latin America, *U. occidentalis* has less items of microplastics in the gills and stomachs than *C. angulatus* and L. *uruguayensis* (Truchet et al., 2022). In contrast, *N. granulata, C. sapidus* and *M. mercenaria* presented lower values than *U. occidentalis* (Villagran et al., 2020; Capparelli et al., 2022) (Table 2). Although, there was no correlation between the number of microplastics in the mangrove crab and the sediment (Pearson: R = -0.02; *p*-value >0.05), there's a possibility that *U. occidentalis* interact with the presence of microplastics in the upper intertidal sediment from the Coastal Upper Zone, Channel Upper Zone, and Tourist Central Zone (Díaz-Jaramillo et al., 2021; Truchet et al., 2022) (S1 and S2A—C).

U. occidentalis is a detritivorous species that mainly ingests decaying leaves from the mangrove *Rhizophora mangle* (Ariza Gallego et al., 2023; Not et al., 2020; Zambrano and Meiners, 2018) and therefore microplastics within their stomachs likely stem from those found in the sediment and adhered to mangrove leaves. It has been shown that microplastics can be transferred through the food chain in different environments (Gutow et al., 2016; Chae et al., 2018; Chae and An, 2020). For example, in terrestrial food chain microplastics transferred from the sediments to a primary producer *Vigna radiata* and then to the snail *Achatina fulica* (Chae and An, 2020), in marine food chain from the seaweed *Fucus vesiculosus* to the periwinkle *Littorina littorea* (Gutow et al., 2016) and in freshwater food chain from microalgae *Chlamydomonas reinhardtii* to *Daphnia magna* and finally to the fish *Zacco*

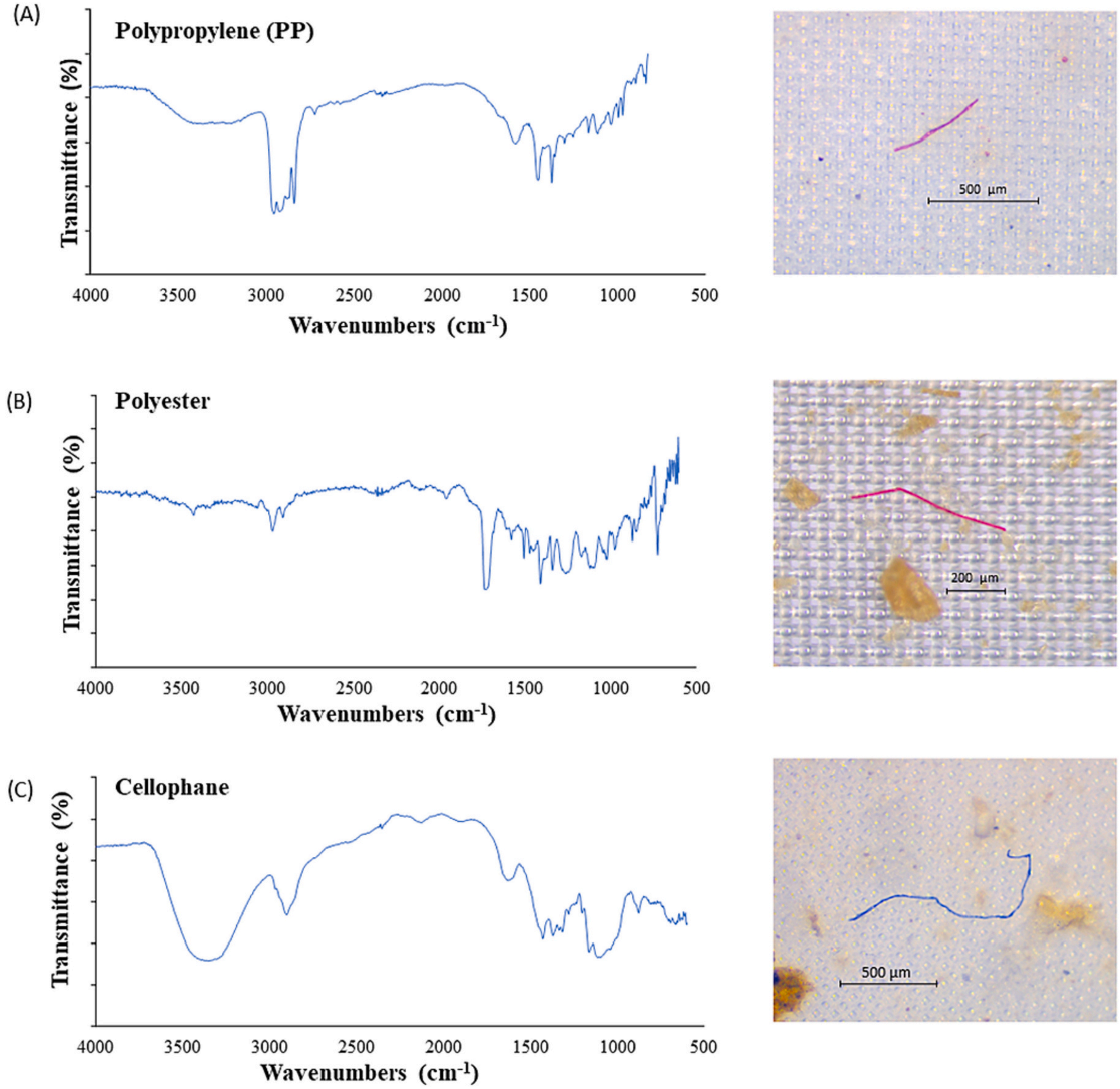

Fig. 5. FT-IR spectra from fibres showing (A) Polypropylene, (B) Polyester and (C) Cellophane spectrum.

Table 1
Estimated human intake of microplastics from the consumption of mangrove crab (*Ucides occidentalis*) and black ark (*Anadara tuberculosa*) from Tumbes region.

	Tumbes Region General population (≥ 10 years)
Per capita mangrove crab consumption (g/capita/year)	174.5
Per capita black ark consumption (g/capita/year)	70.6
Human intake from mangrove crab (MP items/capita/year)	332
Human intake from black ark (MP items/capita/year)	99
Human intake from both species (MP items/capita/year)	431

temminckii (Chae et al.,2018).

The presence of microplastic in the gills and stomach may have physiological and chemical effects in the organism (D'Costa, 2022). For example: exposure to polypropylene fibres and polystyrene spheres reduced food consumption, gill function and scope for growth (i.e. energy) in the crab *Carcinus maenas* (Watts et al., 2014, 2015); a long term exposure to polypropylene fibres, polyethylene terephthalate fragments and microbeads led to weight loss in the crab *Rhithropanopeus harrisii* (Torn, 2020); polystyrene spheres increase the oxidative stress, decrease immune enzyme activity, immune-related gene expression and alteration in the intestinal microflora in the crab *Eriocher sinensis* (Liu et al., 2019; Yu et al., 2018); microplastics were shown to block the opening of the gastrointestinal tract preventing regurgitation and thus increase the retention of microplastics in the stomach in *Eriocheir sinensis* (McGoran et al., 2020); and the accumulation of microplastics in the gills of the crabs *Leptuca festae* and *Minuca ecuadoriensis* reduce gas exchange in the gill's chamber and thus respiratory rate and osmoregulatory functions (Villegas et al., 2021).

Crustaceans don't have an adaptive immune system (D'Costa, 2022; Huang et al., 2020) Nevertheless, decapods have several mechanisms that might be used to eliminate microplastics from the gills and stomach (D'Costa, 2022). In the gills, crabs can remove the particles by brushing it with their chelipeds, by epipods on the thoracic appendages that cause filament jostle, and by a behaviour called "gill grooming" commonly use to expel microbes (D'Costa, 2022; Waite et al., 2018). The removal of microplastic from the stomach is through excretion and regurgitation as a result of stressful conditions (D'Costa, 2022; McGaw and Curtis, 2013).

Table 2
Comparison of microplastic abundance (items/g) in commercial invertebrates from mangrove and estuary ecosystems.

	Studied area	Species	Microplastic abundance (items/ind)	Microplastic abundance (items/g)	Most common shape	Most frequent size (m)	Most common colour	Reference
Crabs	Hong Kong, China	*Parasesarma bidens*	Average 60.5	–	Fragments and beads	> 10	Blue (87 %)	Not et al. (2020)
		Paraleptuca splendida		–	Fibres			
		Metopograpsus frontalis		–	Fragment and beads			
		Thalamita crenata		–	Fragments, beads and fibres.			
	Jakarta Bay, Indonesia	*Metopograpsus quadridentatus*	327.56	33	Fibres and Films	–	–	Mufti et al. (2020)
	Beibu Gulf, China	*Chiromantes dehaani*	0.74–4.96	–				Zhang et al. (2021)
	Buenaventura Bay, Colombia	*Goniopsis pulchra*	9.07 ± 3.7	4.57± 4.14	Fragments and fibres	>9	Transparent and blue	Ariza Gallego et al. (2023)
	Mangrove wetlands of Hainan, South China	Uca vocans	0.22	–	Fibres	0–1 mm	Brown and blue	Zhang et al. (2023)
		Uca arcuata	1.16	–				
		Perisesarma bidens	1.07	–				
		Uca dussuimeri	2.00	–				
		Helicana wuana	0.78	–				
		Sesarma plicata	1.36	–				
	Bahía Blanca Estuary, Argentina	*Neohelice granulata*	–	Gills: ≥ 5.80 Digestive tract: ≥ 0.24	Fibres	<500–1500	Blue	Villagran et al. (2020)
	Bahía Blanca Estuary, Argentina	*Nohelice granulata*	–	Gills: 0.17 ± 0.14	Fibre	<0.5 mm	Transparent and black	Truchet et al. (2022)
		Cyrtograpsus angulatus	–	Gills: 0.11 ± 0.07	Fibre	<0.5 mm	Transparent and black	
		Leptuca uruguayensis	–	Gills: 1 ± 1	Fibre	<0.5 mm	Transparent and black	
	Laguna de Terminos, Mexico	*Callinectes sapidus*	–	37.9	Fragments and fibres	≥ 0.9 mm	Red and blue	Capparelli et al. (2022).
		Menippe mercenaria	–	76	Fragments	≥ 2 mm	Blue	
	Tumbes, Peru	*Ucides occidentalis*	7.8 ± 3.14	Total: 1.94 ± 0.87 Gills: 4 0.1 ± 2.41 Stomach: 0.8 ± 0.7	Fibres	500	Transparent and blue	Present study
Bivalves	Pangkal Babu, Indonesia	*Anadara granosa*	434± 97.05	9.8 ± 2.26	Fibres	–	–	Fitri and Patria (2019)
	Buenaventura Bay, Colombia	*Anadara similis*	17.8 ± 12.98	4.29 ± 4.09	Fragments and fibres	>9	Transparent and blue	Ariza Gallego et al. (2023)
		Anadara tuberculosa	35.39 ± 27.56	4.65 ± 4.64				
	Jeneponto Coast, Indonesia	Anadara granosa	–	1.455–3.806	Line, fragments and films	–	Blue	Daud et al. (2023)
	Mangrove wetlands of Hainan, South China	*Vignadula atrata*	0.22	–	Fibres		Brown and blue	Zhang et al. (2023)
		Geloina erosa	0.23	–				
		Saccostrea echinata	1.85	–				
	Itapessoca estuary in Pernambuco, Brazil	*Anomalocardio flexuosa*	5.15 ± 3.80	3.66 ± 2.59	Fragments	17–1057	–	Bruzaca et al. (2022)
	Situbondo, Indonesia	*Geloina erosa*	15.55 ± 8.51	1.72 ± 1.58	Fibre	–	–	Yona et al. (2023)
	Southwest Coast estuary, India	*Perna viridis*	–	Digestive gland: 5.6 Gills: 8.5	Fibre	1–2 mm	Red	Joshy et al. (2022)
	Tumbes, Peru	*Anadara tuberculosa*	4.9 ± 2.18	1.56 ± 1.12	Fibres	500	Transparent and blue	Present study

-: Not found.

Depending on the species and its gut physiology, there would be differences in the rates of microplastic elimination, which was shown in the crab *Carcinus maenas* who took over six times longer to expel microplastics from the body compared to the typical excretory period (Watts et al., 2014).

4.3. *Mangrove and estuary bivalves*

In the present study the microplastic abundance in the soft tissue of *A. tuberculosa* was 1.56 ±1.12 items/g or 4.9 ± 2.18 items/ind, which is lower than observed in *A. tuberculosa* (4.65 ± 4.64 items/g or 35.39 ± 27.56 items/ind) from Buenaventura Bay, Colombia, *A. flexuosa, G. erosa y P. viridis* from Brazil, Indonesia and India (Table 2) (Ariza Gallego et al., 2023; Bruzaca et al., 2022; Yona et al., 2023; Joshy et al., 2022). Other Anadara species have also been shown to have high levels of microplastic contamination (Table 2), including *Anadara granosa* (9.8 ± 2.26 items/g - 434 ± 97.05 items/ind) and *Anadara similis* (4.29 ± 4.09 items/g - 17.8 ± 12.98 items/ind) from Indonesia and Colombia, respectively (Ariza Gallego et al., 2023; Fitri and Patria, 2019). The main pathway of microplastic uptake in mollusc is ingestion (Wang et al., 2021) with microplastics potentially accumulating in the gills and digestive glands (Green et al., 2019). Microplastics can also adhere to bivalves: pervading the shells, mantle and foot for a long period (Kolandhasamy et al., 2018).

The abundance of microplastics in bivalves tend to vary following the variation of the microplastic number in the associated near-by matrix (Joshy et al., 2022), however, in the present study there was no significant correlation between the abundances of microplastics in sediment and in the black ark. The main sources of microplastic pollution in bivalves are associated with anthropogenic activities such as tourism, aquaculture and artisanal fishing (Bruzaca et al., 2022). Notably the greatest abundance of microplastics in *A. tuberculosa* was in the Rural Central Zone and Tourist Central Zone (S1, S2B), which are surrounded by shrimp farms (Fig. 1). Microplastic exposure can cause an ecotoxicological risk for molluscs (Sussarellu et al., 2016). Studies under laboratory conditions, demonstrate an interference in the reproductive performance reducing sperm velocity and possibly lowering their ability to fertilize oocytes in the oyster *Crassotrea gigas* (Sussarellu et al., 2016); significantly decreases the growth rate of *Mytilus* spp. (Walkinshaw et al., 2023); presents inflammatory responses, lysosomal destabilization and the formation of granulocytomas in *Mytilus edulis* (von Moos et al., 2012); in addition to cellular effects altering immunological responses, changes gene expression profile and genotoxicity in *Mytilus galloprovincialis y Mytilus edulis* (Avio et al., 2015; Cole et al., 2020). In recent years, there has been notable a decrease in the population of *A. tuberculosa* observed in Tumbes (Ordinola Zapata, 2022), which may be attributed to pollution, potentially including microplastics.

Thus, Bivalves have an important role as environmental bioindicators to monitor microplastic pollution (Ding et al., 2021; Staichak et al., 2021). Due to their filter-feeding behaviour allowing the capture of significant amounts of microplastics in the wild and in laboratory environment (Staichak et al., 2021; Wesch et al., 2016). In addition, their easy with which they can be collected, the fact they are ubiquitous and that they interact with the surrounding environment (Ward et al., 2019).

4.4. *Food security and human health*

The presence of microplastic in commercial species is a concern for human health (De-la-Torre, 2020). Consumers that eat microplastic-contaminated food, especially organisms that are consumed whole (i.e. including the gills and digestive tract where microplastics are prevalent) are at high risk of consuming microplastics (Mercogliano et al., 2020; Smith et al., 2018). Microplastics have been identified in a wide array of beverages and foodstuffs including water, beer, salt, sugar, honey, marine finfish and shellfish (Afrin et al., 2022; Al Naggar et al., 2023; Baechler et al., 2020; Lundebye et al., 2022; Senathirajah et al., 2021). In Peru, both species can be consumed whole in traditional dishes (Azabache Cobeña, 2016; Aguirre-Sanchez et al., 2022).

Various predictions have been made of how many microplastics might be consumed by humans through dietary means, European shellfish consumers are estimated to have an annual exposure of 11,000 MPs/person/year (Li et al., 2021; Van Cauwenberghe and Janssen, 2014) while the global average rate of microplastic intake through shellfish consumption is estimated at 2602–16288 items/capita/year (Senathirajah et al., 2021). In Tumbes, the estimated human intake of microplastics is 332 items/capita/year from the mangrove crab, 99 items/capita/year from the black ark and 431 items/capita/year from both species (Table 1). However, food is just one route by which humans can be exposed to microplastics. For example, a number of studies have demonstrated the ubiquity with which microplastics are found in the air we breathe (Amato-Lourenço et al., 2021; Gasperi et al., 2018; Sridharan et al., 2021), with an estimated between 13.731 and 68.415 microplastics per year per capita expected to settle on a plate during a meal exceeding those likely ingested from consuming the food on the plate (Catarino et al., 2018). The risks posed to humans by inhaling or ingesting microplastics may include oxidative stress (Deng & Zhang, 2019), affectation of gene expression and cell morphology (Forte et al., 2016), aggravating allergic diseases (Lu et al., 2022), genotoxic and neurotoxic effects (Oliveira & Almeida, 2019). Of additional concern is that microplastics may act as vectors of pathogenic microbes, metals or persistent organic pollutants (Caruso, 2019), human pathogens, such as bacteria (Ghosh et al., 2021), can colonize plastic surfaces (biofouling) when they come into contact with wastewater treatment plants (Kaiser et al., 2017; Oberbeckmann et al., 2015; Vethaak and Leslie, 2016).

Additionally, these discarded polymers can retain stagnant water in the sediment, creating habitats for parasites and viruses like Dengue and Zika, posing a risk to densely populated and flood-prone areas (Vethaak and Leslie, 2016). The Tumbes region is vulnerable to the persistence of autochthonous Zika virus cases in infants, children, adults, and pregnant women since 2016 (Solis et al., 2018). Furthermore, the presence of total coliforms, thermotolerant coliforms, and *Vibrio* sp. in *A. tuberculosa* (Pernía et al., 2019; Zapata Vidaurre, 2017), as well as *Escherichia coli, Salmonella* spp., and *Pseudomonas* spp. in the meat of *U. occidentalis* (Guamán Quishpi, 2012), poses a risk to the health and food security of the inhabitants of Tumbes (Mercogliano et al., 2020).

Further, microplastics may be trophically-transferred to natural predators in the food web (Maghsodian et al., 2022). The natural predators from *U. occidentalis* and *A. tuberculosa* include the great egret (*Ardea alba*), the tiger heron (*Trigrisoma mexicanum*), the little blue heron (*Egretta caerulea*) and the crab racoon (*Procyon cancrivorus)* which may ingest microplastics via consumption of the mangrove invertebrates (Diele and Koch, 2010; Maghsodian et al., 2022).

4.5. *Physicochemical properties*

The bioavailability of microplastics in mangrove species depends on their size, colour, and shape (Browne et al., 2008). The small sizes found in the crab (Fig. 4d) were due to the ability to fractionate their food in the cardiac stomach and prevent the passage of large particles through filtering silks in the pyloric stomach (Córdova-Ortiz, 2015). The buoyancy of the fibres and the difficulty to remove them from the soft tissue (Zhang et al., 2020; Ziajahromi et al., 2017; Maghsodian et al., 2022) made them the most common shape of microplastic found in both commercial species (Table 2).

The predominant microplastics in living organisms associated to the mangrove ecosystem have a bright colour (Fig. 4d), however, despite not being attractive to the biota, transparent microplastics can blend in with their environment and eventually be ingested (Ma et al., 2020a,Ma et al., 2020b). The polymers identified may stem from a wide range of sources, including packaging, abandoned, lost and discarded fishing gears (ALDFG) or wastewater very common in tourist zones as Puerto Pizarro Bay, which may be particularly problematic given the lack of wastewater treatment in Tumbes (SUNASS (Superintendencia Nacional de Servicios de Saneamiento), 2010).

5. Conclusion

Widespread anthropogenic activity, such as improper waste disposal, shrimp farms, tourism, agriculture and border trade, generate a homogeneous distribution of microplastics abundance throughout the region, which is accumulating in sediments throughout the Tumbes mangrove. Notably, microplastic concentrations within the mangroves represent some of the highest microplastic concentrations in Peru, indicating that mangroves are accumulating microplastics more readily than unvegetated habitats. Microplastics were identified in the tissues of commercially exploited mangrove species. In the mangrove crab microplastics were more prevalent on the gills, indicating they are the main pathway of microplastic uptake and/or retained more readily on the gills than the digestive tract. The presence of microplastics in commercially exploited species poses a risk to consumers, including marine predators and humans. With the local population likely to ingest 431 microplastics/capita/year from consuming black arc and mangrove crab. The outcomes of this work highlight that the mangrove ecosystem is widely contaminated with microplastics, and this may pose a risk to the marine food web and food security.

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CRediT authorship contribution statement

Angelica Aguirre-Sanchez: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Sara Purca:** Conceptualization, Funding acquisition, Project administration, Resources, Supervision, Validation, Writing – review & editing. **Matthew Cole:** Conceptualization, Investigation, Methodology, Resources, Supervision, Validation, Visualization, Writing – review & editing. **Aldo G. Indacochea:** Conceptualization, Methodology, Supervision, Validation, Visualization, Writing – review & editing. **Penelope K. Lindeque:** Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration of Conflicting Interests.

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2024.116075.

References

Afrin, S., Rahman, M.M., Hossain, M.N., Uddin, M.K., Malafaia, G., 2022. Are there plastic particles in my sugar? A pioneering study on the characterization of microplastics in commercial sugars and risk assessment. Sci. Total Environ. 837, 155849 https://doi.org/10.1016/j.scitotenv.2022.155849.

Aguirre-Sanchez, A., Purca, S., Indacochea, A.G., 2022. Microplastic presence in the mangrove crab Ucides occidentalis (Brachyura: Ocypodidae) (Ortmann, 1897) derived from local Markets in Tumbes, Peru. Air, Soil and Water Research 15, 11786221221124548. https://doi.org/10.1177/11786221221124549.

Al Naggar, Y., Sayes, C.M., Collom, C., Ayorinde, T., Qi, S., El-Seedi, H.R., Paxton, R.J., Wang, K., 2023. Chronic exposure to polystyrene microplastic fragments has no effect on honey bee survival, but reduces feeding rate and body weight. Toxics 11 (2), 100. https://doi.org/10.3390/toxics11020100. Jan 21.

Alemán, S., Ordinola, E., 2017. Ampliación de la distribución sur de Ucides occidentalis (Decapoda: Ucididae) y Cardisoma crassum (Decapoda: Gecarcinidae). Revista Peruana de Biología 24 (1), 107–110. https://doi.org/10.15381/rpb.v24i1.13110.

Alongi, D.M., 2020. Carbon cycling in the World's mangrove ecosystems revisited: significance of non-steady state diagenesis and subsurface linkages between the Forest floor and the Coastal Ocean. Forests 11 (9), Article 9. https://doi.org/10.3390/f11090977.

Amato-Lourenço, L.F., Carvalho-Oliveira, R., Júnior, G.R., dos Santos Galvão, L., Ando, R.A., Mauad, T., 2021. Presence of airborne microplastics in human lung tissue. J. Hazard. Mater. 416, 126124 https://doi.org/10.1016/j.jhazmat.2021.126124.

Angulo, F., 2014. Los manglares del Perú. Xilema 27, 5–9. https://doi.org/10.21704/x.v27i1.168.

Ariza Gallego, M.A., Peña Salamanca, E.J., Palacios Peñaranda, M.L., Quesada Mora, C. A., Cantera Kintz, J., 2023. Presence of Microplastics in Macroinvertebrates of Mangroves in the Colombian Pacific: Are Feeding Behaviors Determinant for its Abundance? (SSRN Scholarly Paper N.o 4384915) https://doi.org/10.2139/ssrn.4384915.

Avio, C.G., Gorbi, S., Milan, M., Benedetti, M., Fattorini, D., d'Errico, G., Pauletto, M., Bargelloni, L., Regoli, F., 2015. Pollutants bioavailability and toxicological risk from microplastics to marine mussels. Environ. Pollut. 198, 211–222. https://doi.org/10.1016/j.envpol.2014.12.021.

Azabache Cobeña, J.M.F., 2016. Cadena productiva de *Anadara tuberculosa* (Sowerby 1833) extraída en el Santuario Nacional de los Manglares de Tumbes, 2015 [Undergraduate Thesis]. Universidad Nacional de Tumbes.

Baechler, B.R., Stienbarger, C.D., Horn, D.A., Joseph, J., Taylor, A.R., Granek, E.F., Brander, S.M., 2020. Microplastic occurrence and effects in commercially harvested north American finfish and shellfish: current knowledge and future directions. Limnology and Oceanography Letters 5 (1), 113–136. https://doi.org/10.1002/lol2.10122.

Bråte, I.L.N., Hurley, R., Iversen, K., Beyer, J., Thomas, K.V., Steindal, C.C., Green, N.W., Olsen, M., Lusher, A., 2018. Mytilus spp. as sentinels for monitoring microplastic pollution in Norwegian coastal waters: a qualitative and quantitative study. Environmental pollution (barking, Essex: 1987) 243 (Pt A), 383–393. https://doi.org/10.1016/j.envpol.2018.08.077.

Brennecke, D., Ferreira, E.C., Costa, T.M.M., Appel, D., da Gama, B.A.P., Lenz, M., 2015. Ingested microplastics (>100μm) are translocated to organs of the tropical fiddler crab Uca rapax. Mar. Pollut. Bull. 96 (1), 491–495. https://doi.org/10.1016/j.marpolbul.2015.05.001.

Browne, M.A., Dissanayake, A., Galloway, T.S., Lowe, D.M., Thompson, R.C., 2008. Ingested microscopic plastic Translocates to the circulatory system of the mussel, Mytilus edulis (L.). Environ. Sci. Technol. 42 (13), 5026–5031. https://doi.org/10.1021/es800249a.

Bruzaca, D.N., Justino, A.K., Mota, G.C., Costa, G.A., Lucena-Frédou, F., Gálvez, A.O., 2022. Occurrence of microplastics in bivalve molluscs *Anomalocardia flexuosa* captured in Pernambuco, Northeast Brazil. Marine Pollution Bulletin 179, 113659. https://doi.org/10.1016/j.marpolbul.2022.113659.

Cabanillas, R., Advíncula, O., Gutiérrez, C., 2016. Diversidad de Polychaeta (Annelida) en el intermareal de los esteros del Santuario Nacional los Manglares de Tumbes, Perú. Revista Peruana de Biología 23 (2), 117–126. https://doi.org/10.15381/rpb.v23i2.12383.

Canchari Madueño, F., Iannacone, J., 2022. Microplastics in irrigation canals sediments in the populated center of madean, Madean district, Yauyos Province, Lima region, Peru. Biologist 20, 85–92. https://doi.org/10.24039/rtb20222011318.

Capparelli, M.V., Gómez-Ponce, M.A., Borges-Ramírez, M.M., Rendón-von Osten, J., Celis-Hernández, O., Briceño-Vera, A.E., Ávila, E., Moulatlet, G.M., 2022. Ecological traits influence the bioaccumulation of microplastics in commercially important estuarine crabs from the southeastern Gulf of Mexico. Mar. Pollut. Bull. 183, 114088 https://doi.org/10.1016/j.marpolbul.2022.114088.

Caruso, G., 2019. Microplastics as vectors of contaminants. Mar. Pollut. Bull. 146, 921–924. https://doi.org/10.1016/j.marpolbul.2019.07.052.

Catarino, A.I., Macchia, V., Sanderson, W.G., Thompson, R.C., Henry, T.B., 2018. Low levels of microplastics (MP) in wild mussels indicate that MP ingestion by humans is minimal compared to exposure via household fibres fallout during a meal. Environ. Pollut. 237, 675–684. https://doi.org/10.1016/j.envpol.2018.02.069.

Chae, Y., An, Y.J., 2020. Nanoplastic ingestion induces behavioral disorders in terrestrial snails: trophic transfer effects via vascular plants. Environ. Sci. Nano 7 (3), 975–983. https://doi.org/10.1039/C9EN01335K.

Chae, Y., Kim, D., Kim, S.W., An, Y.J., 2018. Trophic transfer and individual impact of nano-sized polystyrene in a four-species freshwater food chain. Sci. Rep. 8 (1), 284. https://doi.org/10.1038/s41598-017-18849-y.

Clark, J.R., Cole, M., Lindeque, P.K., Fileman, E., Blackford, J., Lewis, C., Lenton, T.M., Galloway, T.S., 2016. Marine microplastic debris: A targeted plan for understanding and quantifying interactions with marine life. Front. Ecol. Environ. 14 (6), 317–324. https://doi.org/10.1002/fee.1297.

Cole, M., Liddle, C., Consolandi, G., Drago, C., Hird, C., Lindeque, P.K., Galloway, T.S., 2020. Microplastics, microfibres and nanoplastics cause variable sub-lethal responses in mussels (*Mytilus* spp.). Mar. Pollut. Bull. 160, 111552 https://doi.org/10.1016/j.marpolbul.2020.111552.

Cole, M., Lindeque, P., Halsband, C., Galloway, T.S., 2011. Microplastics as contaminants in the marine environment: A review. Mar. Pollut. Bull. 62 (12), 2588–2597. https://doi.org/10.1016/j.marpolbul.2011.09.025.

Cole, M., Artioli, Y., Coppock, R., Galli, G., Saad, R., Torres, R., Vance, T., Yunnie., A., Lindeque, P.K, 2023. Mussel power: Scoping a nature-based solution to microplastic debris. J. Hazard. Mater. 453, 131392 https://doi.org/10.1016/j.jhazmat.2023.131392.

Conservación Internacional Peru, 2023. Proyecto sensibilización sobre la basura marina y la contaminación por plásticos en el Santuario Nacional Los Manglares de Tumbes (SNLMT), financiado por la Embajada de Estados Unidos (Informe Interno). Lima, Peru.

Contreras, L.L.S., Quispe, A.L.H., Mendiola, O.J.Á., 2022. Micro plástico: una amenaza imperceptible en la Playa Agua Dulce, distrito de Chorrillos. Revista del Instituto de investigación de la Facultad de minas, metalurgia y ciencias geográficas 25 (49), 303–311. https://doi.org/10.15381/iigeo.v25i49.19219.

Coppock, R.L., Cole, M., Lindeque, P.K., Queirós, A.M., Galloway, T.S., 2017. A small-scale, portable method for extracting microplastics from marine sediments. Environ. Pollut. 230, 829–837. https://doi.org/10.1016/j.envpol.2017.07.017.

Cordova, M.R., Ulumuddin, Y.I., Purbonegoro, T., Shiomoto, A., 2021. Characterization of microplastics in mangrove sediment of Muara Angke wildlife reserve, Indonesia. Marine Pollution Bulletin 163, 112012. https://doi.org/10.1016/j.marpolbul.2021.112012.

Córdova-Ortiz, D.A., 2015. Estudio de Línea Base de los Servicios Ecosistémicos de Provisión y Aportes a Modelos de Gobernanza Local de Conservación y Restauración Inclusiva en el Ecosistema de Manglar del Bajo Lempa, Estero Jaltepeque. Centro Agronómico Tropical para la Investigación y la Enseñanza (CATIE), El Salvador-Agencia Estadounidense de Cooperación Internacional para el Desarrollo (USAID), Programa Regional de Cambio Climático (PRCC), San Salvador, El Salvador, 152 p.

Cozzolino, L., Nicastro, K.R., Zardi, G.I., de Los Santos, C.B., 2020. Species-specific plastic accumulation in the sediment and canopy of coastal vegetated habitats. Sci. Total Environ. 723, 138018 https://doi.org/10.1016/j.scitotenv.2020.138018.

Crawford, C.B., Quinn, B., 2017. Microplastic Pollutants, 1st ed. Elsevier. https://doi.org/10.1016/C2015-0-04315-5.

Daniel, D.B., Ashraf, P.M., Thomas, S.N., Thomson, K.T., 2021. Microplastics in the edible tissues of shellfishes sold for human consumption. Chemosphere 264, 128554. https://doi.org/10.1016/j.chemosphere.2020.128554.

Daud, A., Ishak, H., Amqam, H., Wahyu, A., Birawida, A.B., Mallongi, A., Saleh, R., 2023. Spatial distribution of microplastic contamination in blood clams (Anadara granosa) on the Jeneponto Coast, South Sulawesi. Journal of Namibian Studies: History Politics Culture 34, 2154–2179. https://doi.org/10.59670/jns.v34i.1481.

Dávila, Y.A., Vasquez, R.L.M., 2021. Análisis de la presencia de microplásticos en la arena de las playas de la costa sur del Perú. SINCRETISMO 1 (1), 5–9.

D'Costa, A.H., 2022. Microplastics in decapod crustaceans: accumulation, toxicity and impacts, a review. Sci. Total Environ. 832, 154963 https://doi.org/10.1016/j.scitotenv.2022.154963.

Dehaut, A., Cassone, A.-L., Frère, L., Hermabessiere, L., Himber, C., Rinnert, E., Rivière, G., Lambert, C., Soudant, P., Huvet, A., Duflos, G., Paul-Pont, I., 2016. Microplastics in seafood: benchmark protocol for their extraction and characterization. Environ. Pollut. 215, 223–233. https://doi.org/10.1016/j.envpol.2016.05.018.

De-la-Torre, G.E., 2020. Microplastics: An emerging threat to food security and human health. J. Food Sci. Technol. 57 (5), 1601–1608. https://doi.org/10.1007/s13197-019-04138-1.

De-la-Torre, G.E., Dioses-Salinas, D.C., Castro, J.M., Antay, R., Fernández, N.Y., Espinoza-Morriberón, D., Saldaña-Serrano, M., 2020. Abundance and distribution of microplastics on sandy beaches of Lima, Peru. Marine Pollution Bulletin 151, 110877. https://doi.org/10.1016/j.marpolbul.2019.110877.

Deng, H., He, J., Feng, D., Zhao, Y., Sun, W., Yu, H., Ge, C., 2021. Microplastics pollution in mangrove ecosystems: A critical review of current knowledge and future directions. Sci. Total Environ. 753, 142041 https://doi.org/10.1016/j.scitotenv.2020.142041.

Deng, Y., Zhang, Y., 2019. Response to Uptake of microplastics and related health effects: a critical discussion of Deng et al., Scientific reports 7: 46687, 2017. Arch. Toxicol. 93, 213–215. https://doi.org/10.1007/s00204-018-2384-8.

Díaz-Jaramillo, M., Islas, M.S., Gonzalez, M., 2021. Spatial distribution patterns and identification of microplastics on intertidal sediments from urban and semi-natural SW Atlantic estuaries. Environ. Pollut. 273, 116398 https://doi.org/10.1016/j.envpol.2020.116398.

Diele, K., Koch, V., 2010. Comparative population dynamics and life histories of north Brazilian mangrove crabs, genera *uca* and *Ucides* (Ocypodoidea). In: Saint-Paul, U., Schneider, H. (Eds.), *Mangrove Dynamics and Management in North Brazil. Ecological Studies* (Vol.211). Springer, Berlin, Heildelberg, pp. 275–285.

Ding, J., Sun, C., He, C., Li, J., Ju, P., Li, F., 2021. Microplastics in four bivalve species and basis for using bivalves as bioindicators of microplastic pollution. Sci. Total Environ. 782, 146830 https://doi.org/10.1016/j.scitotenv.2021.146830.

Dioses Puelles, J.E., 2020. Determinación y evaluación de la cobertura vegetal a través de parcelas de monitoreo permanente en el Santuario Nacional los Manglares de Tumbes—Perú. Universidad Nacional de Tumbes.. https://repositorio.untumbes.edu.pe/handle/20.500.12874/2328

Doyle, D., Sundh, H., Almroth, B.C., 2022. Microplastic exposure in aquatic invertebrates can cause significant negative effects compared to natural particles-A meta-analysis. Environ. Pollut., 120434 https://doi.org/10.1016/j.envpol.2022.120434.

Duan, J., Han, J., Cheung, S.G., Chong, R.K.Y., Lo, C.-M., Lee, F.W.-F., Xu, S.J.-L., Yang, Y., Tam, N.F., Zhou, H.-C., 2021. How mangrove plants affect microplastic distribution in sediments of coastal wetlands: case study in Shenzhen Bay, South China. Sci. Total Environ. 767, 144695 https://doi.org/10.1016/j.scitotenv.2020.144695.

Fitri, S., Patria, M.P., 2019. Microplastic contamination on Anadara granosa Linnaeus 1758 in Pangkal Babu mangrove forest area, Tanjung Jabung Barat district, Jambi. Journal of Physics: Conference Series 1282 (1), 012109. https://doi.org/10.1088/1742-6596/1282/1/012109.

Forte, M., Iachetta, G., Tussellino, M., Carotenuto, R., Prisco, M., De Falco, M., et al., 2016. Polystyrene nanoparticles internalization in human gastric adenocarcinoma cells. Toxicol. Vitro 31, 126–136. https://doi.org/10.1016/j.tiv.2015.11.006.

Fu, Q., Tan, X., Ye, S., Ma, L., Gu, Y., Zhang, P., Chen, Q., Yang, Y., Tang, Y., 2021. Mechanism analysis of heavy metal lead captured by natural-aged microplastics. Chemosphere 270, 128624. https://doi.org/10.1016/j.chemosphere.2020.128624.

Garcés Ordóñez, O., Olaya, V., Granados, A., Blandón Garcia, L., Espinosa, L., 2019. Marine litter and microplastic pollution on mangrove soils of the Ciénaga Grande de Santa Marta, Colombian Caribbean. Mar. Pollut. Bull. 145, 455–462. https://doi.org/10.1016/j.marpolbul.2019.06.058.

Gasperi, J., Wright, S.L., Dris, R., Collard, F., Mandin, C., Guerrouache, M., Langlois, V., Kelly, F.J., Tassin, B., 2018. Microplastics in air: are we breathing it in? Current Opinion in Environmental Science & Health 1, 1–5. https://doi.org/10.1016/j.coesh.2017.10.002.

Gavilanez Garcia, L.E., 2016. Estudio de la concentración del plomo en el agua del Rio Tumbes Periodo 2012–2015 como causa de la minería aurifera y su relación con la salud de los pobladores del Caserío de Rica Playa – Tumbes—2016 [Tesis de Doctorado]. Universidad Nacional de Tumbes.. https://repositorio.untumbes.edu.pe/handle/20.500.12874/272

Ghosh, S., Sarkar, T., Chakraborty, R., 2021. Formation and development of biofilm-an alarming concern in food safety perspectives. Biocatal. Agric. Biotechnol. 38, 102210 https://doi.org/10.1016/j.bcab.2021.102210.

Green, D.S., Colgan, T.J., Thompson, R.C., Carolan, J.C., 2019. Exposure to microplastics reduces attachment strength and alters the haemolymph proteome of blue mussels (Mytilus edulis). Environmental pollution (barking, Essex: 1987) 246, 423–434. https://doi.org/10.1016/j.envpol.2018.12.017.

Guamán Quishpi, F. M. (2012). Estudio de la calidad microbiologíca y organoleptíca de pulpa de cangrejo rojo ucides occidentalis [BachelorThesis, Machala: Universidad Técnica de Machala]. http://repositorio.utmachala.edu.ec/handle/48000/1901.

Gutow, L., Eckerlebe, A., Giménez, L., Saborowski, R., 2016. Experimental evaluation of seaweeds as a vector for microplastics into marine food webs. Environ. Sci. Technol. 50 (2), 915–923. https://doi.org/10.1021/acs.est.5b02431.

Hamid, F., Binti, S., Jia, W., Zakaria, R.M., 2020. Microplastics abundance and uptake by Meretrix lyrata (hard clam) in mangrove Forest. Journal of Engineering and Technological Sciences 52(3), Article 3. https://doi.org/10.5614/j.eng.technol.sci.2020.52.3.10.

Hamilton, B.M., Baak, J.E., Vorkamp, K., Hammer, S., Granberg, M., Herzke, D., Provencher, J.F., 2022. Plastics as a carrier of chemical additives to the Arctic: possibilities for strategic monitoring across the circumpolar north. Arctic Science. https://doi.org/10.1139/as-2021-0055.

Hastuti, A. R., Lumbanbatu, D. T., & Wardiatno, Y. (2019). The presence of microplastics in the digestive tract of commercial fishes off Pantai Indah Kapuk coast, Jakarta, Indonesia. Biodiversitas journal of biological diversity, 20(5), article 5. Doi:10.13057/biodiv/d200513.

Henry, B., Laitala, K., Klepp, I.G., 2019. Microfibres from apparel and home textiles: prospects for including microplastics in environmental sustainability assessment. Sci. Total Environ. 652, 483–494. https://doi.org/10.1016/j.scitotenv.2018.10.166.

Hilmi, N., Chami, R., Sutherland, M.D., Hall-Spencer, J.M., Lebleu, L., Benitez, M.B., Levin, L.A., 2021. The role of blue carbon in climate change mitigation and carbon stock conservation. Frontiers in Climate 3. https://www.frontiersin.org/articles/10.3389/fclim.2021.710546.

Huang, J.-N., Wen, B., Zhu, J.-G., Zhang, Y.-S., Gao, J.-Z., Chen, Z.-Z., 2020. Exposure to microplastics impairs digestive performance, stimulates immune response and induces microbiota dysbiosis in the gut of juvenile guppy (Poecilia reticulata). Sci. Total Environ. 733, 138929 https://doi.org/10.1016/j.scitotenv.2020.138929.

Iannacone, J., Huyhua, A., Alvariño, L., Valencia, F., Príncipe, F., Minaya Angoma, D., Ortega Alfaro, J., Pérez, A. and Castañeda Pérez, L., (2020). Microplastics in the high and supralitorial area of a sand beach of the coastal coast of Peru. 17 (2), 335–346.

INEI, 2018 (Instituto Nacional de Estadística e Informática). Resultados definitivos. Población Económicamente Activa del departamento de Tumbes de los Censos Nacionales 2017: XII de Población, VII de Vivienda y III de Comunidades Indígenas. Tomo 1. Presidencia del Consejo de Ministros. https://www.inei.gob.pe/media/MenuRecursivo/publicaciones_digitales/Est/Lib1630/.

INRENA (2007). Plan maestro del Santuario Nacional: Los Manglares de Tumbes 2007–2011.

Iroegbu, A.O.C., Ray, S.S., Mbarane, V., Bordado, J.C., Sardinha, J.P., 2021. Plastic pollution: A perspective on matters arising: challenges and opportunities. ACS Omega 6 (30), 19343–19355. https://doi.org/10.1021/acsomega.1c02760.

Jarosz, K., Janus, R., Wądrzyk, M., Wilczyńska-Michalik, W., Natkański, P., Michalik, M., 2022. Airborne microplastic in the atmospheric deposition and how to identify and quantify the threat: semi-quantitative approach based on Kraków case study. Int. J. Environ. Res. Public Health 19 (19), 12252. https://doi.org/10.3390/ijerph191912252.

John, J., Nandhini, A.R., Velayudhaperumal Chellam, P., Sillanpää, M., 2022. Microplastics in mangroves and coral reef ecosystems: A review. Environ. Chem. Lett. 20 (1), 397–416. https://doi.org/10.1007/s10311-021-01326-4.

Joshy, A., Sharma, S.K., Mini, K.G., 2022. Microplastic contamination in commercially important bivalves from the southwest coast of India. Environ. Pollut. 305, 119250 https://doi.org/10.1016/j.envpol.2022.119250.

Kaiser, D., Kowalski, N., Waniek, J.J., 2017. Effects of biofouling on the sinking behavior of microplastics. Environ. Res. Lett. 12 (12), 124003 https://doi.org/10.1088/1748-9326/aa8e8b.

Kolandhasamy, P., Su, L., Li, J., Qu, X., Jabeen, K., Shi, H., 2018. Adherence of microplastics to soft tissue of mussels: A novel way to uptake microplastics beyond ingestion. Sci. Total Environ. 610-611, 635–640. https://doi.org/10.1016/j.scitotenv.2017.08.053.

Komiyama, A., Ong, J.E., Poungparn, S., 2008. Allometry, biomass, and productivity of mangrove forests: A review. Aquat. Bot. 89 (2), 128–137. https://doi.org/10.1016/j.aquabot.2007.12.006.

Kovač Viršek, M., Palatinus, A., Koren, Š., Peterlin, M., Horvat, P., Kržan, A., 2016. Protocol for microplastics sampling on the sea surface and sample analysis. Journal of Visualized Experiments: JoVE 118, 55161. https://doi.org/10.3791/55161.

Kühn, S., van Werven, B., van Oyen, A., Meijboom, A., Bravo Rebolledo, E.L., van Franeker, J.A., 2017. The use of potassium hydroxide (KOH) solution as a suitable approach to isolate plastics ingested by marine organisms. Mar. Pollut. Bull. 115 (1), 86–90. https://doi.org/10.1016/j.marpolbul.2016.11.034.

Kühn, S., Booth, A.M., Sørensen, L., van Oyen, A., van Franeker, J.A., 2020. Transfer of additive chemicals from marine plastic debris to the stomach oil of northern fulmars. Frontiers in environmental. Science 8. https://www.frontiersin.org/articles/10.3389/fenvs.2020.00138.

Lazarich Gener, R., Rivas, F., & Argüello, G. (2008). Estudio de mercado de la concha negra (Anadara similis y Anadara tuberculosa) en Nicaragua: Comercialización con garantía de inocuidad. Recuperado 20 de abril de 2023, de https://core.ac.uk/display/35144844?utm_source=pdf&utm_medium=banner&utm_campaign=pdf-decoration-v1.

Li, Q., Ma, C., Zhang, Q., Shi, H., 2021. Microplastics in shellfish and implications for food safety. Curr. Opin. Food Sci. 40, 192–197. https://doi.org/10.1016/j.cofs.2021.04.017.

Li, Q., Su, L., Ma, C., Feng, Z., Shi, H., 2022. Plastic debris in coastal macroalgae. Environ. Res. 205, 112464 https://doi.org/10.1016/j.envres.2021.112464.

Li, R., Zhang, S., Zhang, L., Yu, K., Wang, S., Wang, Y., 2020. Field study of the microplastic pollution in sea snails (Ellobium chinense) from mangrove forest and their relationships with microplastics in water/sediment located on the north of Beibu gulf. Environmental pollution (barking, Essex: 1987) 263 (Pt B), 114368. https://doi.org/10.1016/j.envpol.2020.114368.

Lin, L., Chen, C.C., Zhu, X., Pan, K., Xu, X., 2022. Risk of aquaculture-derived microplastics in aquaculture areas: an overlooked issue or a non-issue? Frontiers in Marine Science 9. https://www.frontiersin.org/articles/10.3389/fmars.2022.923471.

Liu, Z., Yu, P., Cai, M., Wu, D., Zhang, M., Chen, M., Zhao, Y., 2019. Effects of microplastics on the innate immunity and intestinal microflora of juvenile Eriocheir sinensis. Sci. Total Environ. 685, 836–846. https://doi.org/10.1016/j.scitotenv.2019.06.265.

Losno Prado, A. G. (2020). Caracterización de microplásticos en agua y sedimentos en los humedales Los Pantanos de Villa, Chorrillos, Lima, Perú.[Tesis de Licenciatura] Universidad Científica del Sur. doi:10.21142/tl.2020.1377.

Lozano, Y.M., Aguilar-Trigueros, C.A., Onandia, G., Maaß, S., Zhao, T., Rillig, M.C., 2021. Effects of microplastics and drought on soil ecosystem functions and multifunctionality. J. Appl. Ecol. 58 (5), 988–996. https://doi.org/10.1111/1365-2664.13839.

Lu, K., Zhan, D., Fang, Y., Li, L., Chen, G., Chen, S., Wang, L., 2022. Microplastics, potential threat to patients with lung diseases. Front. Toxicol. 4, 958414 https://doi.org/10.3389/ftox.2022.958414.

Lundebye, A.K., Lusher, A.L., Bank, M. S, 2022. Marine microplastics and seafood: implications for food security. Microplastic in the environment: Pattern and process 131. https://doi.org/10.1007/978-3-030-78627-4_5.

Lusher, A.L., Welden, N.A., Sobral, P., Cole, M., 2017. Sampling, isolating and identifying microplastics ingested by fish and invertebrates. Anal. Methods 9 (9), 1346–1360. https://doi.org/10.1039/C6AY02415G.

Lusher, A.L., Bråte, I.L.N., Munno, K., Hurley, R.R., Welden, N.A., 2020. Is it or Isn't it: the importance of visual classification in microplastic characterization. Appl. Spectrosc. 74 (9), 1139–1153. https://doi.org/10.1177/0003702820930733.

Ma, H., Pu, S., Liu, S., Bai, Y., Mandal, S., Xing, B., 2020a. Microplastics in aquatic environments: toxicity to trigger ecological consequences. Environ. Pollut. 261, 114089 https://doi.org/10.1016/j.envpol.2020.114089.

Ma, H., Pu, S., Liu, S., Bai, Y., Mandal, S., Xing, B., 2020b. MPs in aquatic environments: toxicity to trigger ecological consequences. Environ. Pollut. 261, 114089 https://doi.org/10.1016/j.envpol.2020.114089.

Maghsodian, Z., Sanati, A.M., Ramavandi, B., Ghasemi, A., Sorial, G.A., 2021. Microplastics accumulation in sediments and Periophthalmus waltoni fish, mangrove forests in southern Iran. Chemosphere 264, 128543. https://doi.org/10.1016/j.chemosphere.2020.128543.

Maghsodian, Z., Sanati, A.M., Tahmasebi, S., Shahriari, M.H., Ramavandi, B., 2022. Study of microplastics pollution in sediments and organisms in mangrove forests: A review. Environ. Res. 208, 112725 https://doi.org/10.1016/j.envres.2022.112725.

Manrique Muñante, R.E., 2019. Microplásticos sedimentos fluviales de la cuenca baja y desembocadura del río Jequetepeque, Perú [Tesis de Maestría]. Pontificia Universidad Católica del Perú, Lima, Perú. https://tesis.pucp.edu.pe/repositorio/handle/20.500.12404/15030.

Martin, C., Almahasheer, H., Duarte, C.M., 2019. Mangrove forests as traps for marine litter. Environ. Pollut. 247, 499–508. https://doi.org/10.1016/j.envpol.2019.01.067.

Martínez, G. (2021). Relaciones sociales de poder y desarrollo territorial en la creación de áreas naturales protegidas: Caso del Santuario Nacional Los Manglares de Tumbes (SNLMT). [Tesis de Doctorado] Pontificia Universidad Católica del Perú https://tesis.pucp.edu.pe/repositorio/handle/20.500.12404/18668.

McGaw, I.J., Curtis, D.L., 2013. A review of gastric processing in decapod crustaceans. J. Comp. Physiol. B 183 (4), 443–465. https://doi.org/10.1007/s00360-012-0730-3.

McGoran, A.R., Clark, P.F., Smith, B.D., Morritt, D., 2020. High prevalence of plastic ingestion by Eriocheir sinensis and Carcinus maenas (Crustacea: Decapoda: Brachyura) in the Thames estuary. Environ. Pollut. 265, 114972 https://doi.org/10.1016/j.envpol.2020.114972.

Meera, S.P., Bhattacharyya, M., Nizam, A., Kumar, A., 2022. A review on microplastic pollution in the mangrove wetlands and microbial strategies for its remediation. Environ. Sci. Pollut. Res. 29 (4), 4865–4879. https://doi.org/10.1007/s11356-021-17451-0.

Mercogliano, R., Avio, C.G., Regoli, F., Anastasio, A., Colavita, G., Santonicola, S., 2020. Occurrence of microplastics in commercial seafood under the perspective of the human food chain. A review. J. Agric. Food Chem. 68 (19), 5296–5301. https://doi.org/10.1021/acs.jafc.0c01209.

Mohamed Nor, N.H., Obbard, J.P., 2014. Microplastics in Singapore's coastal mangrove ecosystems. Mar. Pollut. Bull. 79 (1), 278–283. https://doi.org/10.1016/j.marpolbul.2013.11.025.

Montaluisa Balcázar, K.R., Sánchez Cuenca, D.N., 2021. Diagnóstico de la calidad del agua del canal internacional Zarumilla frente actividades antrópicas mediante parámetros físicoquímicos y biológicos [Tesis de Bachiller]. Universidad Politécnica Salesiana, Ecuador. http://dspace.ups.edu.ec/handle/123456789/20026.

von Moos, N., Burkhardt-Holm, P., Köhler, A., 2012. Uptake and effects of microplastics on cells and tissue of the blue mussel Mytilus edulis L. after an experimental exposure. Environ. Sci. Technol. 46 (20), 11327–11335. https://doi.org/10.1021/es302332w.

Moran Avila, B. (2017). Evaluación de impactos ambientales en la Bahía Puerto Pizarro de la región Tumbes año 2014.[Tesis de Doctorado].Universidad Nacional de Tumbes, Perú.

Morán, B., Hidalgo, A., 2018. Impactos ambientales en la Bahía Puerto Pizarro. Manglar 13 (2), 43–51.

Mufti, P., Santoso, C., Hanifah, N., 2020. Microplastic ingestion by periwinkle snail Littoraria scabra and mangrove crab Metopograpsus quadridentata in Pramuka Island, Jakarta Bay, Indonesia. Sains Malaysiana 49, 2151–2158. https://doi.org/10.17576/jsm-2020-4909-13.

Naji, A., Nuri, M., Vethaak, A.D., 2018. Microplastics contamination in molluscs from the northern part of the Persian Gulf. Environ. Pollut. 235, 113–120. https://doi.org/10.1016/j.envpol.2017.12.046.

Naji, A., Nuri, M., Amiri, P., Niyogi, S., 2019. Small microplastic particles (S-MPPs) in sediments of mangrove ecosystem on the northern coast of the Persian Gulf. Mar. Pollut. Bull. 146, 305–311. https://doi.org/10.1016/j.marpolbul.2019.06.033.

Napper, I. E., & Thompson, R. C. (2019). Chapter 22 - marine plastic pollution: Other than microplastic. En T. M. Letcher & D. A. Vallero (Eds.), Waste (Second Edition) (pp. 425–442). Academic Press. doi:https://doi.org/10.1016/B978-0-12-815060-3.00022-0.

Not, C., Lui, C.Y.I., Cannicci, S., 2020. Feeding behavior is the main driver for microparticle intake in mangrove crabs. Limnology and Oceanography Letters 5 (1), 84–91. https://doi.org/10.1002/lol2.10143.

Oberbeckmann, S., Löder, M.G.J., Labrenz, M., 2015. Marine microplastic-associated biofilms – a review. Environ. Chem. 12 (5), 551–562. https://doi.org/10.1071/EN15069.

Ordinola, E., Montero, P., Alemán, S., Llanos, J., 2010. El cangrejo de los manglares Ucides occidentalis (ORTMAN) en Tumbes, Perú. Primavera 2007. Informe IMARPE. ISSN: 0378-7702, 37, p. 151.

Oliveira, M., Almeida, M., 2019. The why and how of micro (nano) plastic research. TrAC Trends Anal. Chem. 114, 196–201. https://doi.org/10.1016/j.trac.2019.02.023.

Ordinola, E., Alemán, S., Inga, C., Vera, M., Llanos, J., 2019. Sinopsis biológica, poblacional y pesquera de Anadara tuberculosa (Sowerby, 1833) y Anadara similis (C. B. Adams, 1852) en los manglares de Tumbes: 1995-2015. Bol Inst Mar Perú 223–264.

Ordinola Zapata, E., 2022. Pesquería de invertebrados marinos y de manglar, Tumbes, Perú, 2018. Inf Inst Mar Perú. 49 (1), 5–32. https://repositorio.imarpe.gob.pe/handle/20.500.12958/4050.

da Paes, E.S., Gloaguen, T.V., dos Silva, H.A.C., da Duarte, T.S., de Almeida, M.C., da Costa, O.D.V., Bomfim, M.R., Santos, J.A.G., 2022. Widespread microplastic pollution in mangrove soils of Todos os Santos Bay, northern Brazil. Environ. Res. 210, 112952 https://doi.org/10.1016/j.envres.2022.112952.

Pernía, B., Mero, M., Cornejo, X., y Zambrano, J. (2019). Impactos de la contaminación sobre los manglares de Ecuador. Manglares de América, 375–419. http://www.manglaresdeamerica.com/index.php/ec/article/view/57.

Prata, J.C., Reis, V., da Costa, J.P., Mouneyrac, C., Duarte, A.C., Rocha-Santos, T., 2021. Contamination issues as a challenge in quality control and quality assurance in microplastics analytics. J. Hazard. Mater. 403, 123660 https://doi.org/10.1016/j.jhazmat.2020.123660.

Purca, S., Henostroza, A., 2017. Presencia de microplásticos en cuatro playas arenosas de Perú. Rev. Peru. Biol. 24 (1), 101–106. https://doi.org/10.15381/rpb.v24i1.12724.

R Core Team, 2020. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.r-project.org/index.html.

Rovai, A.S., Twilley, R.R., Worthington, T.A., Riul, P., 2022. Brazilian mangroves: blue carbon hotspots of national and global relevance to natural climate solutions. Frontiers in forests and global. Change 4. https://www.frontiersin.org/articles/10.3389/ffgc.2021.787533.

Senathirajah, K., Attwood, S., Bhagwat, G., Carbery, M., Wilson, S., Palanisami, T., 2021. Estimation of the mass of microplastics ingested – A pivotal first step towards human health risk assessment. J. Hazard. Mater. 404, 124004 https://doi.org/10.1016/j.jhazmat.2020.124004.

Smith, M., Love, D.C., Rochman, C.M., Neff, R.A., 2018. Microplastics in seafood and the implications for human health. Current Environmental Health Reports 5 (3), 375–386. https://doi.org/10.1007/s40572-018-0206-z.

Solis, M., Gines, E., Hernández, E., 2018. Aplicación de Tecnologías de Análisis Geoespacial en la Evaluación de la Situación Epidemiológica del Zika en la Región Tumbes. Manglar 14 (2), 95–106. https://doi.org/10.17268/manglar.

Sridharan, S., Kumar, M., Singh, L., Bolan, N.S., Saha, M., 2021. Microplastics as an emerging source of particulate air pollution: A critical review. J. Hazard. Mater. 418, 126245 https://doi.org/10.1016/j.jhazmat.2021.126245.

Staichak, G., Ferreira-Jr, A.L., Moreschi Silva, A.C., Girard, P., Callil, C.T., Christo, S.W., 2021. Bivalves with potential for monitoring microplastics in South America. Case Studies in Chemical and Environmental Engineering 4, 100119. https://doi.org/10.1016/j.cscee.2021.100119.

SUNASS (Superintendencia Nacional de Servicios de Saneamiento). (2010). Plan Maestro optimizado de la empresa prestadora de servicios de Saneamiento S.A para el periodo 2010-2039. Recuperado 13 de julio de 2023, de SUNASS website: https://www.sunass.gob.pe/websunass/.

Sussarellu, R., Suquet, M., Thomas, Y., Lambert, C., Fabioux, C., Pernet, M.E.J., Le Goïc, N., Quillien, V., Mingant, C., Epelboin, Y., Corporeau, C., Guyomarch, J., Robbens, J., Paul-Pont, I., Soudant, P., Huvet, A., 2016. Oyster reproduction is affected by exposure to polystyrene microplastics. Proc. Natl. Acad. Sci. 113 (9), 2430–2435. https://doi.org/10.1073/pnas.1519019113.

Taillardat, P., Friess, D.A., Lupascu, M., 2018. Mangrove blue carbon strategies for climate change mitigation are most effective at the national scale. Biol. Lett. 14 (10), 20180251. https://doi.org/10.1098/rsbl.2018.0251.

Tan, E., Mohd Zanuri, N.B., 2023. Abundance and distribution of microplastics in tropical estuarine mangrove areas around Penang, Malaysia. Frontiers in marine. Science 10. https://www.frontiersin.org/articles/10.3389/fmars.2023.1148804.

Tineo Nuñez, B.G., Periche Viera, R.E., 2019. Evaluación del contenido de metales pesados en la margen izquierda del valle del río Tumbes y su absorción por el cultivo de arroz durante el periodo Marzo–Julio 2018.[Undergraduate Thesis]. Universidad Nacional de Tumbes.

Torn, K., 2020. Microplastics uptake and accumulation in the digestive system of the mud crab Rhithropanopeus harrisii. Proceedings of the Estonian Academy of Sciences 69 (1), 35–42. Scopus. https://doi.org/10.3176/proc.2020.1.04.

Truchet, D.M., Ardusso, M.G., Forero-López, A.D., Rimondino, G.N., Buzzi, N.S., Malanca, F., Spetter, C.V., Fernández-Severini, M.D., 2022. Tracking synthetic microdebris contamination in a highly urbanized estuary through crabs as sentinel species: An ecological trait-based approach. Sci. Total Environ. 837, 155631 https://doi.org/10.1016/j.scitotenv.2022.155631.

Van Cauwenberghe, L., Janssen, C.R., 2014. Microplastics in bivalves cultured for human consumption. Environ. Pollut. 193, 65–70. https://doi.org/10.1016/j.envpol.2014.06.010.

Vethaak, A.D., Leslie, H.A., 2016. Plastic debris is a human health issue. Environ. Sci. Technol. 50 (13), 6825–6826. https://doi.org/10.1021/acs.est.6b02569.

Villagran, D.M., Truchet, D.M., Buzzi, N.S., Lopez, A.D.F., Severini, M.D.F., 2020. A baseline study of microplastics in the burrowing crab (*Neohelice granulata)* from a temperate southwestern Atlantic estuary. Mar. Pollut. Bull. 150, 110686 https://doi.org/10.1016/j.marpolbul.2019.110686.

Villegas, L., Cabrera, M., Capparelli, M.V., 2021. Assessment of microplastic and organophosphate pesticides contamination in fiddler crabs from a Ramsar site in the estuary of Guayas River, Ecuador. Bull. Environ. Contam. Toxicol. 107 (1), 20–28. https://doi.org/10.1007/s00128-021-03238-z.

Waite, H.R., Donnelly, M.J., Walters, L.J., 2018. Quantity and types of microplastics in the organic tissues of the eastern oyster Crassostrea virginica and Atlantic mud crab Panopeus herbstii from a Florida estuary. Mar. Pollut. Bull. 129 (1), 179–185. https://doi.org/10.1016/j.marpolbul.2018.02.026.

Walkinshaw, C., Tolhurst, T.J., Lindeque, P.K., Thompson, R.C., Cole, M., 2023. Impact of polyester and cotton microfibers on growth and sublethal biomarkers in juvenile mussels. Microplastics and Nanoplastics 3 (1), 5. https://doi.org/10.1186/s43591-023-00052-8.

Wang, R., Mou, H., Lin, X., Zhu, H., Li, B., Wang, J., Junaid, M., Wang, J., 2021. Microplastics in mollusks: research Progress, current contamination status, analysis approaches, and future perspectives. Frontiers in marine. Science 8. https://www.frontiersin.org/articles/10.3389/fmars.2021.759919.

Ward, J.E., Zhao, S., Holohan, B.A., Mladinich, K.M., Griffin, T.W., Wozniak, J., Shumway, S.E., 2019. Selective ingestion and egestion of plastic particles by the blue mussel (Mytilus edulis) and eastern oyster (Crassostrea virginica): implications for using bivalves as bioindicators of microplastic pollution. Environ. Sci. Technol. 53 (15), 8776–8784. https://doi.org/10.1021/acs.est.9b02073.

Watts, A.J.R., Lewis, C., Goodhead, R.M., Beckett, S.J., Moger, J., Tyler, C.R., Galloway, T.S., 2014. Uptake and retention of microplastics by the shore crab Carcinus maenas. Environ. Sci. Technol. 48 (15), 8823–8830. https://doi.org/10.1021/es501090e.

Watts, A.J.R., Urbina, M.A., Corr, S., Lewis, C., Galloway, T.S., 2015. Ingestion of plastic microfibers by the crab Carcinus maenas and its effect on food consumption and energy balance. Environmental science and technology 49 (24), 14597–14604. Scopus. https://doi.org/10.1021/acs.est.5b04026.

Wesch, C., Bredimus, K., Paulus, M., Klein, R., 2016. Towards the suitable monitoring of ingestion of microplastics by marine biota: A review. Environmental Pollution (Barking, Essex: 1987) 218, 1200–1208. https://doi.org/10.1016/j.envpol.2016.08.076.

van Wezel, A., Caris, I., Kools, S.A.E., 2016. Release of primary microplastics from consumer products to wastewater in the Netherlands. Environ. Toxicol. Chem. 35 (7), 1627–1631. https://doi.org/10.1002/etc.3316.

Yona, D., Mahendra, B.A., Fuad, M.A.Z., Sartimbul, A., 2023. Microplastics contamination in molluscs from mangrove forest of Situbondo, Indonesia. In: IOP Conference Series: Earth and Environmental Science, Vol. 1191, No. 1. IOP Publishing. https://doi.org/10.1088/1755-1315/1191/1/012016, p. 012016.

Yu, P., Liu, Z., Wu, D., Chen, M., Lv, W., Zhao, Y., 2018. Accumulation of polystyrene microplastics in juvenile Eriocheir sinensis and oxidative stress effects in the liver. Aquat. Toxicol. 200, 28–36. https://doi.org/10.1016/j.aquatox.2018.04.015.

Zambrano, R., Meiners, C., 2018. Notas sobre taxonomía, biología y pesquería de Ucides occidentalis (Brachyura: Ocypodidae) con énfasis en el Golfo de Guayaquil, Ecuador. Revista Peruana de Biología 25 (1). https://doi.org/10.15381/rpb.v25i1.13821. Article 1.

Zapata Vidaurre, K. Y. (2017). Caracterizacion molecular de la microbiota asociada a la sangre y gonadas de la concha negra Anadara tuberculosa. [Tesis de Maestría] Universidad Nacional de Tumbes. https://repositorio.untumbes.edu.pe/handle/20.500.12874/492.

Zárate, M., Iannacone, J., 2021. Microplásticos en tres playas arenosas de la costa central del Perú. Revista de Salud Ambiental 21 (2), 123–131.

Zhang, Q., Xu, E.G., Li, J., Chen, Q., Ma, L., Zeng, E.Y., Shi, H., 2020. A review of microplastics in table salt, drinking water, and air: direct human exposure. Environ. Sci. Technol. 54 (7), 3740–3751. https://doi.org/10.1021/acs.est.9b04535.

Zhang, Q., Xie, J., Ma, S., Chen, Y., Lin, F., Diao, X., 2023. Occurrenceand characteristics of microplastics in benthic species from mangrove wetlands of Hainan, South China. Frontiers in Marine Science 10, 965059. https://doi.org/10.3389/fmars.2023.965059.

Zhang, S., Sun, Y., Liu, B., Li, R., 2021. Full size microplastics in crab and fish collected from the mangrove wetland of Beibu gulf: evidences from Raman tweezers (1-20 μm) and spectroscopy (20-5000 μm). Sci. Total Environ. 759, 143504 https://doi.org/10.1016/j.scitotenv.2020.143504.

Zhao, T., Lozano, Y.M., Rillig, M.C., 2021. Microplastics increase soil pH and decrease microbial activities as a function of microplastic shape, polymer type, and exposure time. Frontiers in environmental. Science 9. https://www.frontiersin.org/articles/10.3389/fenvs.2021.675803.

Ziajahromi, S., Kumar, A., Neale, P.A., Leusch, F.D.L., 2017. Impact of microplastic beads and fibers on Waterflea (Ceriodaphnia dubia) survival, growth, and reproduction: implications of single and mixture exposures. Environ. Sci. Technol. 51 (22), 13397–13406. https://doi.org/10.1021/acs.est.7b03574.

Zuo, L., Sun, Y., Li, H., Hu, Y., Lin, L., Peng, J., Xu, X., 2020. Microplastics in mangrove sediments of the Pearl River estuary, South China: correlation with halogenated flame retardants' levels. Sci. Total Environ. 725, 138344 https://doi.org/10.1016/j.scitotenv.2020.138344.