

Microplastics contamination, polymer – associated hazard, and dietary exposure in commercially important crustaceans from the Palk Strait, Southeast coast of India

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Abstract

Microplastic (MP) contamination in commercially important crustaceans is a growing environmental and food-safety issue. MP abundance, morphological characteristics, polymer composition, polymer hazard index (PHI), and estimated dietary exposure were examined in *Penaeus semisulcatus*, *P. monodon*, and *Portunus pelagicus* from the Palk Strait, southeast coast of India. In total, 300 specimens were examined, comprising *P. monodon* (N = 100), *P. semisulcatus* (N = 100), and *P. pelagicus* (N = 100). MPs were characterised by stereomicroscopy and FTIR-ATR after 10% KOH digestion. The mean MP abundance was 3.42 ± 0.78 items ind⁻¹, with *P. semisulcatus* was highest (4.12 items ind⁻¹) followed by *P. monodon* (3.56 items ind⁻¹) and *Portunus pelagicus* (2.57 items ind⁻¹). Blue and black were common colours for fibres, fragments, and films. FTIR-ATR confirmed HDPE, PP, and PE as the main polymers. According to the polymer hazard index (PHI) values, all three species were classified as level III (high risk), with the highest PHI recorded in *Penaeus monodon* (908), *P. semisulcatus* (795), and *Portunus pelagicus* (731). For adults, the estimated dietary exposure was estimated at 0.057 items kg⁻¹ bw day⁻¹, while for children, was 0.171 items. MP contamination and polymer-associated risks in commercially significant crustaceans suggest seafood intake may expose humans.

1. Introduction

Persistent plastic debris undergoes fragmentation through photochemical degradation, mechanical abrasion, and other weathering processes, resulting in the formation of microplastics (MPs), which are in general defined as plastic particles smaller than 5 mm (Yousafzai et al., 2025; Song et al., 2026). Plastic pollution has become a widespread environmental problem in marine and coastal ecosystems. These particles are now reported in seawater, sediments, and marine biota, reflecting their substantial biological availability and widespread environmental distribution. MPs are derived from both primary sources, such as industrial pellets and synthetic microfibres, and secondary fragmentation of larger plastic debris. When released into aquatic systems, particle size, density, shape, polymer composition, biofouling, and local hydrodynamic conditions all influence movement, settling, and biological uptake. Therefore, MPs have become a major contaminant at the intersection of marine pollution, ecosystem health and seafood safety (Wright et al., 2013; Hara et al., 2020; Kristanti et al., 2022). Hara et al. (2020), for example, identified MPs as frequent in open oceans, coastlines, sediments, and deep-sea environments, emphasising ingestion as a key route of exposure for marine organisms.

Crustaceans are particularly relevant to MP research because they occupy diverse ecological niches and trophic levels in marine and estuarine environments (Doshi et al., 2024; Morris et al., 2025; Aminah et al., 2026). Shrimps, prawns, crabs, and lobsters belong to benthic, epibenthic, omnivorous, predatory, scavenging, and detritivorous species, providing various pathways for both direct and indirect MP uptake (Islam et al., 2026; Yucel & Kilic, 2025; Dias et al., 2024). The ingestion of particles from water, sediment, prey, or detrital material is possible while feeding, and their close association with bottom sediments can further increase exposure to deposited MPs. Therefore, decapod crustaceans have been widely regarded as beneficial organisms for the monitoring of environmental MP contamination and are also essential for the assessment of potential human exposure, as many species are involved in significant commercial fisheries (Ogunola et al., 2022). Based to studies, MPs may be absorbed by marine species due to similarities to natural food particles and trophic transfer (Otiti et al., 2026).

Coastal areas serve as a vital source of seafood, where several high-value species such as shrimps and crabs are cultured. According to the FAO (2016), marine and coastal aquaculture produces around 28 million tons in 2015, with mollusks (65%), crustaceans (28%), and finfish (7%). These values show the economic importance of coastal fisheries and aquaculture. MPs can be transported from the environment to organisms and then through the food chain, i.e., from prey to predator (Kangas et al., 2023). MP ingestion has been observed in many seafood species from throughout the world, including fish (Kilic et al., 2026). Several studies have shown that various species of crabs and shrimp in different marine environments across worldwide ingest MPs (Dias et al., 2024; Wu et al., 2023; Rabari et al., 2023; Aguirre-Sanchez et al., 2022; Daniel et al., 2021). Because of their sensitivity to environmental changes, crabs, which are omnivores that inhabit the ocean floor, are frequently used as indicators of pollution levels (Zhang et al., 2021; Briffa et al., 2024). Previous studies in the Gulf of Mannar (GOM) have examined that heavy metal pollution in sediments (Perumal et al., 2021), the quantity of marine debris (Perumal et al., 2021) and different types of pollution in salts (Perumal et al., 2025); MP pollution in fish (James et al., 2021); and the health of coral reef communities (Marimuthu et al., 2016). In the present research, the distribution of MPs in the gastrointestinal tracts (GT) and tissues of three commercially important crustaceans, mainly *Penaeus semisulcatus*, *P. monodon*, and *Portunus pelagicus*. The estimated dietary exposure of MPs is also computed using the measured contamination levels and consumption-related characteristics in order to investigate the possible consequences for seafood consumers. This study provides a detailed evaluation of the ecological and potential human exposure effects of MP contamination in commercially important crustaceans from Palk Bay, Southeast coast of India, by considering contamination abundance, particle characteristics, polymer composition, pollution indices, PHI, tissue-specific occurrence, and estimated dietary exposure.

2. Materials and methods

2.1 Study area and sample collection

The Palk Bay Strait, which divides the southeast coast of India from the northern coast of Sri Lanka, is roughly 35 km long. As a result, the international boundary is located along the coastlines of both countries. The Palk Bay is habitat to a variety of ecological resources, including diverse seagrass meadows, mangrove forests, mudflats, wetlands, brackish water, saline lagoons, and wildlife sanctuaries (Manikandan et al., 2011; Jagadeesan et al., 2013). The significance of the park is derived from the biosphere and its surroundings, which are home to a diverse array of edible and decorative fish and corals. Mangroves, coral reefs, rocky coasts, sandy beaches, mudflats, seaweed, and seagrass are among the many ecosystems that make up the biosphere. Every habitat supports its own populations by a distinct zonation pattern. Endangered dugongs, sea turtles, migrating whales, dolphins, and porpoises are also well-known along this shore. The 5500 km² Gulf of Mannar (GOM) is well known for its commercial fishing zones and rich pelagic fisheries resources. From specific fish-landing locations throughout the Palk Strait on India's southeast coast, 300 commercially significant crustacean specimens, representing three species, were collected (Fig. 1). *Penaeus monodon* (n = 100), *P. semisulcatus* (n = 100), and *Portunus pelagicus* (n = 100) were among the samples. In the Palk

Bay region, specimens were collected from the major fish-landing locations of Thondi, Kottaiappattinam, Jegathapattinam, and Karankadu. These species were chosen because of their significant importance for seafood consumption in the area, high commercial value, and regular occurrence in local fish landings. The morphometric characteristics of the specimens, including body weight and total length, were recorded before microplastic examination, which were identified following collection using the relevant taxonomic literature.

A standard dissection method was used to separate the entire digestive system from each crustacean specimen. Each of the dissected tissues was placed into a clean, marked 50-mL glass bottle. Following Rochman et al. (2015), the samples were treated with 10% potassium hydroxide (KOH) and incubated in a water bath at 60°C for 24 hours in order to decompose the organic material and extract MPs. Following full digestion, 0.45-µm Whatman filters were used to filter the resultant solutions. Before being examined under a microscope, the filters were moved to sterile Petri dishes and let to dry at room temperature. A stereomicroscope (Nikon SMZ 25) with a digital camera was used to examine the dried filters (Fig. 2). Suspected MPs were counted, visually identified, and characterised based on their colour, size, and shape. Particle morphology was categorised into the main groups seen in the samples, including films, fibres, and fragments. MP abundance was calculated using the total number of MPs retrieved from each specimen. Fourier-transform infrared spectroscopy combined with attenuated total reflectance (FTIR–ATR) was used to further characterise the chemical makeup of the extracted particles. The retrieved MPs were classified and polymers were identified using the resultant spectra. The abundance, morphological characteristics, and polymer composition of MPs present in the gastrointestinal tract and tissues of the investigated crustaceans were evaluated through the combination of stereomicroscopic characterisation and FTIR–ATR analysis. FTIR–ATR particles were transferred to the instrument's microplate under a stereomicroscope. Spectrum acquisition averaged 50 scans per sample, over wave number range of 400–4000 cm⁻¹ at 4 cm⁻¹ resolution. The OMNIC™ Spectra program was used to process and compare spectra using libraries. The spectra's peaks were also compared to polymer spectra published by Jung et al., (2018).

2.2 Quality Assurance and Quality Control (QA/QC)

All through the research process, strong quality assurance and quality control (QA/QC) procedures were observed and adhered to in order to reduce the possibility of outside contamination of the samples during processing and analysis. Before being used, all lab equipment, glassware, forceps, Petri dishes, and filtering apparatus were completely cleaned with distilled water and covered with aluminium foil. In order to lessen secondary contamination from airborne synthetic particles, plastic materials were avoided wherever possible. A hygienic laboratory setting was used for all sample preparation and filtering processes. To reduce fibre contamination from clothing, nitrile gloves and cotton lab coats were worn during the investigation. Before and after every experiment, work surfaces were routinely cleansed with distilled water and ethanol. All glass containers were covered when not in use, and the digesting and filtering processes were conducted under regulated conditions. Procedural blank samples with filtered distilled water were treated concurrently with the biological samples using the same digestion, filtration, and observation techniques in order to measure airborne contamination. MPs found in the blanks were noted and taken out of the final abundance calculations. Before sample analysis, the filter papers used for filtering were closely inspected under a stereomicroscope to make sure there were no contaminating particles.

MPs were visually identified using their morphological characteristics, such as size, colour, and shape. Sterilised stainless-steel forceps were used to gently remove suspected particles. To prevent misidentification of non-plastic particles, polymer identification was further verified using FTIR–ATR. For the purpose of identifying polymers, only spectra with adequate matching percentages against reference libraries were considered valid. Every sample was analysed in triplicate wherever feasible to guarantee analytical accuracy and reproducibility, and the results were cross-checked. The QA/QC methods used in this investigation adhered to published guidelines for the analysis of MPs in marine organisms (Rochman et al., 2015; Hermesen et al., 2018).

2.3 Polymer hazard index (PHI)

The various polymer types found in the examined crustaceans were evaluated for possible environmental and toxicological hazards using the PHI. The PHI was computed using the following formula, which combines each polymer's relative abundance with its associated polymer-specific hazard score:

$$PHI = \sum (P_n \times S_n) \dots \dots \dots (1)$$

Where, S_n is the polymer's hazard score and P_n is the percentage (%) of a polymer type in the sample. According to Lithner et al., (2011), the hazard ratings (S_n) for HDPE, PE, PP, polymers in this study are 11, 11, and 1. PHI was categorized as follows: Level I (< 10; low); Level II (10–100; moderate); Level III (101–1,000; high); Level IV (1,001–10,000; very high); Level V (> 10,000; extremely high) (Lithner et al., 2011). In previous studies, the PHI determined in the crustaceans from the marine ecosystem (Doshi et al., 2024; Bar et al., 2025; Chen et al., 2025).

2.4 Estimated dietary exposure to MPs through crustacean

The potential dietary exposure to MPs through the consumption of commercially important crustaceans was assessed using the EDI. A scenario-based exposure approach was used, assuming the consumption of one crustacean individual per day, because MP abundance in the current study was expressed as items individual⁻¹. The EDI was calculated differently for adults and children using this formula:

$$EDI = C_{MP} \times IR / BW \dots \dots \dots (2)$$

Where, BW is the assumed body weight of the consumer (60 kg for adults and 20 kg for children), IR is the expected ingestion rate (1 individual day⁻¹), and C_{MP} is the mean MP abundance in crustaceans (3.42 ± 0.78 items ind⁻¹). EDI was therefore represented as items kg⁻¹ body weight day⁻¹. Although the units of MP concentration, edible portion analysed, seafood ingestion rate, and population-specific body weight all have a major effect on the reliability of such estimates, dietary exposure assessments are frequently used to estimate potential MP intake through seafood consumption (Daniel et al., 2021; Kandeyaya et al., 2023).

The daily estimates were extrapolated to estimated monthly intake (EMI) and estimated annual intake (EAI) in order to investigate potential exposure over longer periods:

$$\text{EMI} = \text{EDI} \times 30 \dots\dots\dots (3)$$

$$\text{EAI} = \text{EDI} \times 365 \dots\dots\dots (4)$$

Where, items kg^{-1} bw month^{-1} and items kg^{-1} bw year^{-1} were used to represent EMI and EAI, respectively. The estimated values were used as scenario-based prospective dietary exposure estimates rather than quantitative human-health risk assessments because globally accepted health-based reference doses or safe intake thresholds for ingested MPs are currently lacking. Furthermore, because the current estimate considers MP abundance per individual rather than concentration specific to gram of edible tissue, the EDI represents a standardised exposure scenario and should be regarded with caution. To increase dietary exposure estimations, future evaluations should preferably measure MP concentrations in edible tissues (items g^{-1} wet weight) and combine these values with population-specific crustacean consumption rates.

3. Results and Discussion

3.1 Abundance of MPs

MPs were found in the guts and tissues of all three commercially important crab species investigated in the Palk Strait. The mean abundance was 3.42 ± 0.78 items ind^{-1} , showing significant MP contamination of crustaceans from this coastal environment (Table 1). *Penaeus semisulcatus* showed the highest mean abundance (4.12 items ind^{-1}), followed by *P. monodon* (3.56 items ind^{-1}) and *Portunus pelagicus* (2.57 items ind^{-1}), while species-wise abundances were very corresponding (Fig. 3). The distribution of observations in the box plots showed inter-individual heterogeneity, but the comparatively small variation between the three species indicates generally similar exposure to MPs within the study area. Variations in dietary habits, habitat utilisation, body size, gastrointestinal contents, and local MP availability may all contribute to this diversity. In contrast to research employing identical items per ind^{-1} unit, the average abundance noted in this investigation was considerably high. *Nephrops norvegicus* from Irish waters had 1.75 ± 2.01 items ind^{-1} , according to Hara et al., (2020), but prawns from the Australian market had roughly 0.8 ± 0.1 items ind^{-1} (Ogunola et al., 2022). Reduced quantities were likewise documented in *Palaemon elegans* from Iran (0.38 items ind^{-1}) and *Melicertus hathor* from Türkiye (0.76 ± 1.0 items ind^{-1}). Similarly, *Callinectes sapidus* and *Pandalus borealis* displayed values of $0.44\text{--}0.72$ and $0.04\text{--}1.67$ items ind^{-1} , respectively (Waddell et al., 2020; Fang et al., 2018), while *Chiromantes dehaani* from the Yangtze Estuary contained 1.48 ± 0.45 items ind^{-1} (Wu et al., 2023). Notably, the average amount of MP found in *Scylla serrata* from Negombo Lagoon, Sri Lanka (11.57 ± 6.29 items ind^{-2} ; Dias et al., 2024) was lower than the average amount observed in this study. Likewise, Zhang et al., (2021) found that among various wild crab species from Chinese fishing sites, there were about $2\text{--}9.81$ items ind^{-1} . These studies suggest a rather high incidence of MP in crustaceans from the Palk Strait, however one must take into account variations in species, environments, and analytical methods. Hossain et al., (2020) reported 3.40 ± 1.23 and 3.87 ± 1.05 items g^{-1} in the gastrointestinal tracts of *P. monodon* and *Metapenaeus monoceros*, correspondingly, from the northern Bay of Bengal. *Metapenaeus affinis* from Musa Bay in the Persian Gulf showed about 1.02 items g^{-1} of digestive tissue (Keshavarzifard et al., 2021), whereas Lawan et al., (2024) reported 8.29 ± 4.63 items g^{-1} in *P. monodon* from Negombo Lagoon. A significantly elevated mass-normalized abundance of 114.7 ± 33.2 items g^{-1} was recorded in the gastrointestinal system of *Litopenaeus vannamei* from Mexico (Valencia-Castaneda et al., 2022). Similar study showed 0.67 ± 0.62 MPs g^{-1} in *Portunus sanguinolentus* from Gujarat (Rabari et al., 2023) and 0.39 ± 0.6 MPs shrimp $^{-1}$ in *Fenneropenaeus indicus* from Cochin (Daniel et al., 2020). As a result, the denominator used to express abundance may partially explain the apparent differences among studies, rather than the actual differences in environmental contamination.

Table 1

Microplastic concentration in different species of crustaceans and corresponding size, shapes, colours, spectroscopy, polymer types reported in studies

Sample region	Species name	Tissue analysed	Abundance of MPs	Size of MPs	Shapes/types of MPs	Colour of MPs	MP detection methods	Type polymer
Palk Strait, Southeast coast of India	<i>Penaeus monodon</i> (100)	Gut and tissue	3.42 items ind ⁻¹	100 to 1000 µm	Fibre, Fragment, Film	Blue, black, green, pink, red, colourless	Stereomicroscopy; FTIR-ATR	HDPE, PP, PA
	<i>Penaeus semisulcatus</i> (50)							
	<i>Portunus pelagicus</i> (100)							
Bantry Bay and North Irish Sea, Ireland	<i>Nephrops norvegicus</i>	Gastrointestinal/digestive tract	1.75 items ind ⁻¹	1–2 mm	Fibres, fragments, films	Blue, black, grey, red, green	Stereomicroscopy; ATR-FTIR; µ-FTIR	PVC, PP, PA
Northern Bay of Bengal, Bangladesh	<i>Penaeus monodon</i>	Gastrointestinal tract	3.40 items g ⁻¹	1–5 mm	Filament, fibre, fragment	Black, white, green, blue, red	Microscopy; µ-FTIR	PA; PET
Musa Bay, Northwest Persian Gulf, Iran	<i>Metapenaeus affinis</i>	Digestive tissues	1.02 items g ⁻¹	> 500 µm	Fibre, film	White, blue, black	Microscopy; Raman spectroscopy	PET, PA
Negombo Lagoon, Sri Lanka	<i>Penaeus monodon</i>	Gastrointestinal tract, gills	8.29 items g ⁻¹	> 1000 µm	Fibres, fragments	Blue, red, black,	Stereomicroscopy; FTIR	PS, PP, PA
Negombo fishing harbour, Sri Lanka	<i>Penaeus monodon</i>	Edible and non-edible	1.70 MPs g ⁻¹	N/A	Fibres, fragments, spheres, films, pellets, foam	Blue, transparent, orange, yellow	Stereomicroscopy, µ-FTIR	LDPE, HDPE, PP, PA
Queensland and Northern Territory, Australia	King prawn, <i>Melicertus</i> spp. <i>Penaeus esculentus</i> <i>Penaeus merguensis</i>	Gastrointestinal tract and muscle	0.8 items ind ⁻¹	38 µm – 1 mm	Fibres, fragments	Blue, black, transparent, red	Microscopy; µ-FTIR	PO, PP, PA
Gulf of California, Mexico	<i>Litopenaeus vannamei</i>	Gastrointestinal tract, gills	114.7 items g ⁻¹	403 µm	Fibres, fragments, films	Transparent, blue	µ-FTIR	PET, PA
Northern Bay of Bengal, Bangladesh	<i>Metapenaeus monoceros</i>	Gastrointestinal tract	3.87 items g ⁻¹	250–500 µm	Filament, fibre, fragment	Black, white, blue, green	Microscopy; µ-FTIR	Polyester (PA6), PP
Southern coast of Caspian Sea, Iran	<i>Palaemon elegans</i>	Soft tissues	0.38 items ind ⁻¹	300–1000 µm	Fibre dominant	Black dominant	ATR-FTIR	PA
Bahía Blanca Estuary, southwestern Atlantic, Argentina	<i>Pleoticus muelleri</i>	Muscle with gastrointestinal tract	1.31 items g ⁻¹	1.06 mm	Fibres	Black	Microscopy, µ-Raman, SEM-EDS	PE, PP
Bangladesh	<i>Macrobrachium rosenbergii</i>	Gut, gills and muscle	8.91 items ind ⁻¹	< 0.5 mm	Fibres, fragments	Black, red, blue, green, transparent	Optical microscopy; ATR-FTIR	PVS, Nylon, PET, PA
Mediterranean Sea, Türkiye	<i>Melicertus hathor</i>	Gastrointestinal tract and hepatopancreas	0.6 MPs ind ⁻¹	< 1 mm	Fibres, fragments	Black, blue, red	Stereomicroscopy, ATR-FTIR	PE, PP
Negombo Lagoon, Sri Lanka	<i>Scylla serrata</i>	Gills and gastrointestinal	11.57 items/ind.	0.05–5.00 mm	Fibre	Transparent, blue	µ-FTIR	Rayon
Chongming Island, Yangtze Estuary	<i>Chiromantes dehaani</i>	Tissues	1.48 items/ind.	< 1000 µm	fibers	Dark	µ-FTIR	Rayon
Gujarat, West coast of India	<i>P. sanguinolentus</i>	Gut and gills	0.67 ± 0.62 MPs/g	1–2 mm	Fibers	Black, red, green	ATR-FTIR	PE, PP
Tumbes, Peru	<i>U. occidentalis</i>	Gills and digestive tract	921 MPs	2–250 µm	Fibers, films	Black films	FTIR-ATR	PET, PA

Sample region	Species name	Tissue analysed	Abundance of MPs	Size of MPs	Shapes/types of MPs	Colour of MPs	MP detection methods	Type polyr
Fishing harbours of Kerala, India.	<i>Portunus pelagicus</i>	Tissue	2.7 MP/kg	100–300 µm	Fragments	Transparent - white, blue, black	FTIR	PP; P
Yangtze River Estuary, China	<i>Trituber culatus</i> , <i>Charybdis japonica</i> , <i>Dorippe japonica</i> , <i>Matuta planipes</i>	Tissue	2–9.81 items/ind.	19–4976 µm	Fibre	White, red, yellow, Blue, green	µ-FTIR	PES,
Coastal waters of Cochin, India.	<i>Fenneropenaeus indicus</i>	Gastrointestinal tract	0.39 - MPs/shrimp	157 to 2785 µm	Fibres, fragment, sheets	Red, blue, black, transparent, green	FTIR	PES,
Corpus Christi Bay, Gulf Coast	<i>Callinectes sapidus</i>	Stomach	0.44–0.72 items/ ind.	10 to 400 µm	Fibre, fragment, film	Black, blue, green, red, colourless	ATR-FTIR	Cellu PES, PS
Chukchi and Bering seas continental shelf	<i>Pandalus borealis</i>	Soft tissue and gills	0.04–1.67 items/ind.	1.45 mm	Synthetic fiber; film	Red; transparent; gray	FTIR	PA, P

Abbreviations: Polyvinyl stearate – PVS, polyethylene-propylene-diene – PEPD, Nylon II, Polyolefin – PO, Polyamide – PA, Polyamide-6 - PA6, polyamide (PA), polyethylene (PE), polyester (PES), cellophane (CP), Polyethylene-vinyl acetate – PEVA, Polyethylene terephthalate - PET, polyethylene tetraphene, polyurethane, polystyrene, and polypropylene Polyethylene, polyethylene tetraphene, polyurethane, polystyrene, and polypropylene.

3.3 Size of MPs

MPs isolated from crustaceans' guts and tissues ranged in size from 100 to 1000 µm (Fig. 4A). The selected species, such as *Penaeus monodon* and *Portunus pelagicus*, have greater MPs (> 500 µm), while their guts have MPs ranging from 300 to 400 µm. Crustaceans like *P. semisulcatus* swallowed tiny MPs (< 500 µm), but their stomachs included MPs larger than 100 µm. Previous studies (Hossain et al., 2020; Akhbarizadeh et al., 2019) have shown a majority of particles between 500 and 1000 µm. In previous studies have proven that MPs smaller than 500 µm can translocate into numerous tissues, increasing the risk of their presence in shrimp edible parts (Collard et al., 2017; Jovanovic et al., 2018). According to D'Costa (2023), MP size varies between species based on feeding behaviours. Fang et al., (2018) found MPs smaller than 2 mm in *Chionoecetes opilio*, while Daniel et al. (2021) found MPs between 100 and 200 µm in *Portunus pelagicus*. The presence of MPs of varied sizes in crabs shows that bigger plastic debris was fragmented into smaller particles (Rabari et al., 2023). Furthermore, smaller MPs are more likely to absorb contaminants due to their larger surface area (Robin et al., 2020).

Previous studies of commercially important shrimps found comparable size distributions. Hossain et al., (2020) identified MPs in *P. monodon* and *Metapenaeus monoceros* from the northern Bay of Bengal, measuring between 250 µm to 5 mm. In a study of *P. monodon* and *P. semisulcatus* from the Arabian Sea, ingested MPs were categorised into four size classes: < 250 µm, 250–500 µm, 500 µm–1 mm, and 1–5 mm. *P. semisulcatus* had the highest abundance of particulates < 250 µm, while *P. monodon* contained MPs in all four size classes. Lawan et al., (2024) discovered MPs in Sri Lankan shrimps of various sizes, with particles larger than 1000 µm being more common in *P. monodon* and *P. indicus*. MP size varies significantly across crustaceans, according to studies conducted in Indian seas. Daniel et al. found MPs in tissue samples of commercially important shellfish, such as *Portunus pelagicus*, ranging from 100–300 µm. In another study, MPs in *Fenneropenaeus indicus* were shown to be significantly more in size. Recent findings from Malaysian seas demonstrated that MPs of 500–1000 µm were the main size fraction in *P. monodon*. However, particles from < 100 µm to 3000 µm were identified. These observations show that crustaceans can eat and retain MPs of varying sizes. Differences in MP size between species may reflect species-specific feeding tactics, habitat utilisation, particle availability, gut architecture, and selective ingestion or retention. Smaller MPs may be especially important because their size allows for easier absorption and potentially increased accessibility to biological tissues. However, comparisons between studies should be done with caution because reported size distributions are heavily impacted by sample processes, filter pore size, analytical detection limits, and the use of microscopy, FTIR, or Raman spectroscopy. Thus, the observed variations between the current study and earlier investigations may be due to both biological variability and methodological variances.

3.4 Colour of MPs

The MPs found in *Penaeus monodon*, *P. semisulcatus*, and *Portunus pelagicus* from the Palk Strait were diverse in colour, ranging from blue to black, green, pink, red, and colourless particles (Fig. 4B). This trend is similar with prior research on commercially important crustaceans, in which blue and black MPs were the most commonly observed colours, along with transparent/colorless, red, green, and white particles. Similar colour assemblages have been documented in *P. monodon* and *Metapenaeus monoceros* from the northern Bay of Bengal (Hossain et al., 2020), *Metapenaeus affinis* from the Persian Gulf (Keshavarzifard et al., 2021), *Fenneropenaeus indicus* from India's southwest coast (Daniel et al., 2020), and *P. monodon* from Sri Lanka (Lawan et al., 2024). Colour diversity has also been observed in commercially important crabs such as *Portunus pelagicus*, *P. sanguinolentus*, and *Scylla serrata* (Daniel et al., 2021; Rabari et al., 2023; Dias et al., 2024). The aquatic organisms are mainly visual predators so the study of MPs colors is important (Nelms et al., 2018). While later research refuted this assertion, earlier studies had revealed that colour was an important factor in aquatic species decision to consume something. However, colour may help us determine where MPs come from (Nelms et al., 2018). The prevalence of the colour black is caused by the usage of black threads and ropes in fishing nets. Coloured MPs are produced when coloured plastics break down. In contrast, the deterioration of fishing lines and nets

results in colourless MPs. The source of colored materials can include clothing, packaging supplies, fishing cords, and lines, among other items. The blue and red colored components gradually give way to colorless MPs (Di and Wang, 2018). Blue and red MPs are relatively recent contributions to the environment, as observed by their presence in the study's samples. Colored materials include white or transparent carry bags, packaging supplies, and fishing line (Cole et al., 2014). Similarly, MPs in *Portunus pelagicus* (Kleawkla, 2019) and *Ocypode quadrata* (Costa et al., 2019) were mostly black and blue in color. These colors were most likely derived from discarded black and blue fishing nets, which are a major source of MPs in the marine environment (Rabari et al., 2024).

The prevalent presence of blue and black MPs may indicate the substantial utilisation and degradation of coloured synthetic substances in coastal ecosystems, such as fishing nets, ropes, lines, textiles, marine coatings, and various plastic items (Kutralam-Muniasamy et al., 2023). The comparable prevalence of black and blue MPs has been recorded in the Mediterranean Sea and Indian Ocean, confirming their global distribution across different marine environments (Oza et al., 2024; Adamopoulou et al., 2025). Attribution of sources based on colour should be considered with caution, as photodegradation, photooxidation, biofouling, and visual-identification bias may modify or conceal the original hue of environmentally aged MPs (De Haan et al., 2026). Consequently, the present study's broad colour spectrum implies that the Palk Strait receives a variety of MP inputs and is consistent with the presence of multiple anthropogenic sources that affect crustacean exposure to MP.

3.5 Shapes of MPs

MPs found in *Penaeus monodon*, *P. semisulcatus*, and *Portunus pelagicus* from the Palk Strait were mostly fibres, fragments, and films (Fig. 4C). This suggests that most of the particles were probably secondary MPs that were made when larger plastic materials break down or dispersed. This pattern is consistent with the global literature on decapod crustaceans: a major review found that fibres were the most frequently reported MP morphology in decapods, followed by fragments, while a systematic review of commercially important marine fauna found that fibres were the dominant morphology in 61.1% of crustacean records. *Fenneropenaeus indicus* from Cochin (Daniel et al., 2020), *P. monodon* and *Metapenaeus monoceros* from the northern Bay of Bengal (Hossain et al., 2020), and other commercially significant prawns and crabs have all been shown to have similar combinations of fibres and fragments. Fibres were the dominant MP morphotype, consistent with earlier reports in crustaceans (Hossain et al., 2020; Devriese et al., 2015). Their main sources are likely textiles, fishing gear, and tyre wear, with fibres commonly detected in sediments, surface waters, and marine organisms of this region (Sruthy et al., 2017). A single garment wash can release thousands of fibres, and laundry effluents are a significant contributor (Browne et al., 2011; Napper and Thompson, 2016). Fragments, on the other hand, arise from the breakdown of larger plastics into irregular particles < 5 mm, originating from both marine and terrestrial sources (Ogata et al., 2009). The continuous release of synthetic filaments from fishing nets, ropes, lines, aquaculture materials, textiles, and wastewater may be associated with the predominance of fibres. Furthermore, the progressive weathering and fragmentation of larger plastic products, including plastic bags and packaging materials, are typically associated with fragments and films (Zhang et al., 2021; Ogunola et al., 2022; Lawan et al., 2024). Similarly, global assessments identify fibres and fragments as the most prevalent MP morphologies and suggest that degraded fishing gear and synthetic textiles are significant potential sources of fibres in aquatic environments (Prabhu et al., 2022). The high prevalence of fibrous MPs in crustaceans may also be influenced by their feeding behaviour and close association with contaminated water and sediments; however, morphology alone is insufficient to definitively identify the source of an individual particle. In general, the presence of films, fragments, and fibres in the current study suggests that the Palk Strait receives a variety of multiple and heterogeneous MP inputs, which may include fishing activities, domestic wastewater, coastal settlements, and the degradation of larger plastic debris.

3.6 Chemical characteristics of MPs using FTIR–ATR spectroscopy

Polyethylene (PE), polypropylene (PP), and high-density polyethylene (HDPE) were identified in the FTIR-ATR analysis of MPs obtained from *Penaeus monodon*, *P. semisulcatus*, and *Portunus pelagicus* in the current study. The asymmetric and symmetric stretching vibrations of CH₂ groups were ascribed to the characteristic peaks observed at approximately 2920 and 2850 cm⁻¹, respectively. The CH₂ bending vibrations were allocated the peak at approximately 1465 cm⁻¹, while the CH₂ rocking vibrations were assigned the distinctive peak at 730 cm⁻¹. The polymer was identified as PE as a result of these characteristic absorption bands (Fig. 5A). The prevalence of PE in marine organisms was also demonstrated in previous studies (Daniel et al., 2021; Dias et al., 2024; Parmar et al., 2025; Islam et al., 2026). The C-H stretching vibrations were designated the largest peaks at approximately 2950, 2916, and 2838 cm⁻¹. The bands at 1456 and 1376 cm⁻¹ were attributed to CH₃ bending vibrations, while the peak at 1167 cm⁻¹ was associated with C-C stretching. The rocking and wagging vibrations of CH₃ and CH₂ were determined to be the distinctive maxima at 998, 841, and 809 cm⁻¹, respectively. These unique absorption bands were indicative of the polymer being PP in the microplastic samples using FTIR–ATR spectrum (Fig. 5B). The finding of PP in this investigation is in conformity with earlier studies that reported PP contamination in marine organisms (Daniel et al., 2020, 2021; Kandeyaya et al., 2023; Dias et al., 2024; Bornt et al., 2025; Islam et al., 2026). With absorption bands at 2915 and 2848 cm⁻¹, displaying symmetric and asymmetric stretching vibrations of –CH₂ groups, HDPE was identified in the FTIR–ATR spectra. A strong absorption band at 1465 cm⁻¹ was attributable to CH₂ bending vibrations. The band at 720–730 cm⁻¹ was attributed to CH₂ rocking vibrations in polyethylene's crystalline structure. These diagnostic absorption bands demonstrate that the microplastic particle was HDPE (Fig. 5C). The presence of HDPE in crustaceans was also observed earlier by Kandeyaya et al., (2023).

PP is frequently found in medical components, plastic packaging, textiles, plastic containers, and fishing nets (Jung et al., 2018). The crustaceans that live on the bottom have direct access to these high-density polymers, yet this further research is needed to determine if polymers were ingested by bottom-dwelling. The polymer composition of microplastics in marine organisms is often a result of the contamination by aquaculture activities and fishing gears, with PE and PP with the most prevalent polymers (Castro et al., 2016; Wang et al., 2018; Fok et al., 2020). The high proportions of PP, PE, and PS observed are in accordance with previous research and are indicative of their substantial contribution to global plastic production (Plastics Europe, 2019). PE and PP are frequently sourced from household products, fishing materials, and packaging, although accurate sources are not possible to identify (Jambeck et al., 2015; Cho et al., 2019). According to Rabari et al., (2024) and Song et al., (2023), the accumulation of MPs in marine biota has the potential to induce detrimental impacts on individual species, including but not limited to hunger, growth suppression, reproductive abnormalities, gastrointestinal system blockage, and

mortality. The predominance of PE, HDPE and PP in the Palk Strait may be associated with their extensive application in packaging materials, plastic bags and containers, fishing nets, ropes, sacks and other fisheries-related materials. For example, PE and PP have been linked to common consumer and fishing-related plastic products, and recent shrimp studies have similarly identified PE and PP among the major recovered polymers. Their widespread production, environmental persistence and extensive use in coastal and fishing activities may therefore contribute to their availability for ingestion by crustaceans.

3.7 Polymer hazard index (PHI) in crustaceans

The polymer hazard index of the three crustacean species varied from 731 to 908, with all species classified as within level III (high risk) (Table 2). *Penaeus monodon* presented the highest PHI (908), followed by *P. semisulcatus* (795), and *Portunus pelagicus* (731). HDPE, PE, and PP comprised 36.0%, 44.8%, and 19.2% of the identified polymers in *P. monodon*, respectively. Their respective contributions to the PHI were 396, 492.8, and 19.2. *P. semisulcatus* contained HDPE (21.2%), PE (48.3%), and PP (30.5%), resulting in PHI contributions of 233.2, 531.3, and 30.5, respectively. In *Portunus pelagicus*, the total PHI was 731, with HDPE (22%), PE (41.1%), and PP (36.9%) contributing 242, 452.1, and 36.9, respectively. The level III (high risk) classification of all three species suggests that the crustaceans under investigation are at a comparatively high risk of polymer-associated hazards. The lowest PHI of *P. pelagicus* is partially due to its higher relative proportion of PP, which has a substantially lower hazard score, while the highest value in *P. monodon* is indicative of its combined abundance of HDPE and PE. However, PHI should be interpreted as a screening-level polymer hazard indicator rather than direct evidence of biological toxicity or human-health risk. This is due to the fact that it does not account for particle concentration, size, bioavailability, chemical additives, sorbed contaminants, exposure duration, or dose-response relationships (Kleinteich et al., 2018). As a result, PHI is most effectively analysed in relation to microplastic abundance, particle characteristics, tissue distribution, and dietary-exposure indices to offer a more thorough evaluation of microplastic contamination in commercially significant crustaceans. The FTIR-ATR results reported in the present study were consistent with the observation that HDPE, PP, and PE dominated the overall polymer composition of the samples. PE and PP are also frequently reported among MPs occurring in marine environments and organisms (Andrady, 2011; Jung et al., 2018; Fok et al., 2020). The predominance of these polyolefins may be attributed to their widespread application in packaging, containers, textiles, fishing nets, ropes, and other fisheries-related materials. However, the PHI results should be read as a relative polymer-associated hazard screening metric rather than direct evidence of human-health exposure. Polymer hazard scores are primarily determined by the hazards associated with polymer constituents and associated chemicals. Therefore, PHI does not formally consider environmentally relevant dose, particle bioavailability, weathering, additive leaching, or organism-specific toxicological responses. However, the PHI values of 731–908 show that an evaluation that depends only on the abundance of MPs may understate the differences in the chemical-hazard profiles of ingested plastics.

Table 2
Polymer hazard index (PHI) of microplastics identified in commercially important crustaceans from the Palk Strait

Species	HDPE (%)	Hazard score (HDPE)	PP (%)	Hazard score (PP)	PE (%)	Hazard score (PE)	PHI	Hazard category
<i>Penaeus monodon</i>	36	11	19.2	1	44.8	11	908	Level III – High risk
<i>P. semisulcatus</i>	21.2	11	30.5	1	48.3	11	795	Level III – High risk
<i>Portunus pelagicus</i>	22	11	36.9	1	41.1	11	731	Level III – High risk

3.8 Estimated dietary exposure to MPs through crustacean

The estimated dietary exposure (EDI) was used as a screening-level measure to assess the potential dietary exposure to MPs through the consumption of commercially essential crustaceans (Fig. 6). The estimated exposure for adults (60 kg) and children (20 kg) was 0.057 items kg⁻¹ bw day⁻¹ and 0.171 items kg⁻¹ bw day⁻¹, respectively, based on the mean MP abundance of 3.42 items individual⁻¹ in the present analysis and the assumed consumption of one crustacean individual per day (Table 3). Adults and children were estimated to have an annual exposure of 20.81 and 62.42 items kg⁻¹ bw year⁻¹, respectively, while their monthly exposure was 1.71 and 5.13 items kg⁻¹ bw month⁻¹. The lower assumed body weight of children is the primary factor contributing to the higher body-weight-normalized exposure estimates, rather than a difference in MP contamination. The identification of MPs in commercially significant crustaceans suggests that seafood consumption may serve as a potential route of human exposure. MPs were identified in 48% of decapods crustaceans examined from Australian seafood markets by Ogunola et al., (2022), which included commercially significant prawns and crabs. Daniel et al., (2021) also observed MPs in consumable shellfish tissues from India and estimated an annual dietary intake of approximately 13 ± 58 particles per person per year. However, exposure was contingent upon the species, consumption quantity, and extent of gut removal. Furthermore, Kandeyaya et al. (2023) underscored that the consumption of whole marine organisms may lead to a higher level of MP exposure than consumption after the gastrointestinal tract has been removed. Therefore, the presence of MPs in commercially harvested crustaceans poses a risk to human food exposure as well as an ecological contamination problem. The significance of consumption patterns in estimating potential intake is demonstrated by earlier exposure estimates. According to Hara et al., (2020), depending on the frequency of use, an annual exposure to *N. norvegicus* might be between 15 and 4,471 particles person⁻¹ year⁻¹. Keshavarzifard et al., (2021) calculated an annual intake of around 857 MPs person⁻¹ through *M. affinis* utilising a regional shrimp eating rate of 2.3 g person⁻¹ day⁻¹. However, significant methodological variations in the tissues examined, digestive processes, filter pore sizes, minimum detectable particle sizes, contamination controls, spectroscopic confirmation, and reporting units make it difficult to compare exposure across investigations.

Table 3
Estimated dietary exposure (EDI) to MPs through crustacean

Present study	Population	Daily EDI (items kg ⁻¹ bw day ⁻¹)	Monthly exposure (items kg ⁻¹ bw month ⁻¹)	Annual exposure (items kg ⁻¹ bw year ⁻¹)
Crustaceans from Palk Strait	Adult (60 kg)	0.057	1.71	20.81
	Child (20 kg)	0.171	5.13	62.42

3.8.1 Tissue distribution and implications for dietary exposure

Another significant cause of variation in crustacean investigations is the tissue compartment studied. The gastrointestinal tract and gills have been the focus of most studies since these organs are directly exposed to ingested or suspended particles. Devriese et al., (2015), for example, found synthetic fibres in 63% of brown prawns (*Crangon crangon*) collected from the Southern north Sea and English Channel. Previous research has also found that MPs are more common in gills and digestive tissues than in muscle, possibly due to direct gill contact with suspended particles and retention of ingested MPs within the digestive system (Abbasi et al., 2018; Su et al., 2019). The intake and retention of MPs among crab species may thus be influenced by feeding ecology, particle availability, and morphological characteristics (Collard et al., 2017).

The presence of MPs in edible tissues is very significant for evaluating food safety. LeBlanc et al., (2025) noticed 6.65 ± 5.36 MPs g⁻¹ wet weight in the edible muscle of *Homarus americanus*, whereas Severini et al., (2020) found 1.31 fibres g⁻¹ wet weight in the abdominal muscle of the economically significant shrimp *Pleoticus muelleri*. On the other hand, Zhang et al., (2021) found MPs in the gills and intestines of a number of wild crab species but not in the muscle tissue. Similarly, Kandeyaya et al., (2023) discovered that edible tissues had generally lower MP contamination than non-edible tissues, indicating that removing the gastrointestinal system prior to ingestion may lessen dietary exposure. This differential is crucial because, while little prawns may occasionally be eaten whole, large crustaceans are often gutted before consumption, increasing the possibility of consuming MPs that are retained within the digestive tract (Hossain et al., 2020).

3.9 Potential sources and ecological/food-safety implications

Identification of HDPE, PP, and PE, together with the predominance of fibres, fragments, and films, indicates that MPs in Palk Strait are the result of a combination of land- and sea-based activities. Synthetic garments release substantial quantities of microfibrils during washing, which can result in the entry of fibres into coastal waters through domestic laundry effluent and inadequately treated municipal wastewater (Napper and Thompson, 2016; De Falco et al., 2022). The above may include the abrasion and degradation of fishing nets, ropes, lines, and other fishing materials, which are marine-based sources. Abandoned or discarded fishing gear has also been documented along the Palk Strait coast, which supports fisheries as a plausible local source. In addition, the HDPE, PP, and PE fragments and films may be the result of land discharge, packaging materials, plastic bags, containers, harbour activities, and coastal tourism. Similar microplastic assemblages dominated by fibres have been observed in crustaceans from Ireland, Bangladesh, Sri Lanka, and Australia (Hara et al., 2020; Hossain et al., 2020; Lawan et al., 2024; Ogunola et al., 2022). However, the identification of an exact source is not possible solely based on colour and morphology; confirmation involves comparison with polymers from local fishing gear, wastewater, sediments, and coastal litter.

MPs in the gut and tissues of shrimp and crab species indicate uptake by feeding, sediment contact, and gill. Particle size and shape affected ingestion, retention, and toxicity, according to controlled experiments conducted on grass shrimp; under high exposure environments, small threads had more negative effects than fragments or spheres (Gray and Weinstein, 2017). In other *Litopenaeus vannamei* studies, MP exposure caused gill damage, oxidative stress, and physiological and metabolic disturbance (Xing et al., 2024; Leela, 2025). These impacts may impair feeding efficiency, energy, development, immunity, and reproduction. The current field abundance indicates exposure rather than biological harm; histological, biochemical, and physiological data are needed to confirm ecological impacts. Ingested particles may also travel through coastal food webs since prawns and crabs are benthic consumers and prey for fish, birds, and other predators. Microplastic surfaces can absorb environmental pollutants, bacteria, and additives. MPs can carry contaminants, as *Pleoticus muelleri* edible muscle fibres included PE, PP, and surface-associated substances (Severini et al., 2020). Pollutant transfer and biomagnification cannot be determined from MP abundance alone and require chemical examination of particles and animal tissues. Commercially significant prawn and crab species may expose consumers to MPs, which could compromise food safety. Because the gastrointestinal system has more MP than muscle, eating prawns whole, dried, or undefined may increase exposure. Gut removal may significantly reduce intake but may not remove particles in gills or edible tissues. MPs have been found in edible shrimp tissues and commercial shellfish (Daniel et al., 2020; Severini, 2020). Tran et al., (2026) highlighted substantial knowledge gaps regarding the gastrointestinal absorption of MPs, nanoplastic formation, additive toxicity, chronic exposure, and associated dose-response relationships.

4. Conclusion

The study observed MPs in three commercially important crustaceans, *Penaeus monodon*, *P. semisulcatus*, and *Portunus pelagicus*, from the Palk Strait on India's southeast coast. The average MP abundance was 16.78 pieces per ind⁻¹, with similar contamination across the three species. Fibres, fragments, and films dominated the recovered MPs, which varied in size, colour, and shape. FTIR-ATR analysis identified PE, PP, and HDPE as the main polymers, suggesting that fishing, packaging, coastal settlements, wastewater, and degradation of bigger plastic debris may have caused the pollution. *Penaeus monodon* had a PHI (908), *P. semisulcatus* (795), and *P. pelagicus* (731), placing all three species in level III (high polymer-associated hazard). PE and HDPE contributed most to the high PHI values, while PP contributed less due to its lower polymer hazard score. Dietary exposure evaluation revealed EDI values of 0.280 kg⁻¹ bw day⁻¹ for adults and 0.839 kg⁻¹ bw day⁻¹ for children, with the larger body-weight-normalized estimate for children due to their lower estimated body weight. These findings suggest that commercially relevant crustaceans can link marine MP contamination to human food intake. They should be considered screening-level indicators rather than direct measures of ecological toxicity or human-health danger. Future research should measure MPs in edible and non-

edible tissues, standardize abundance as g⁻¹ wet weight, include local seafood consumption trends, and examine nanoplastics, additives, and sorbed pollutants. Information on MP contamination in crustaceans from the Palk Strait and other tropical coastal environments will improve ecological risk assessment and food-safety assessments.

Statements and Declarations

Declaration of competing interest.

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Figures

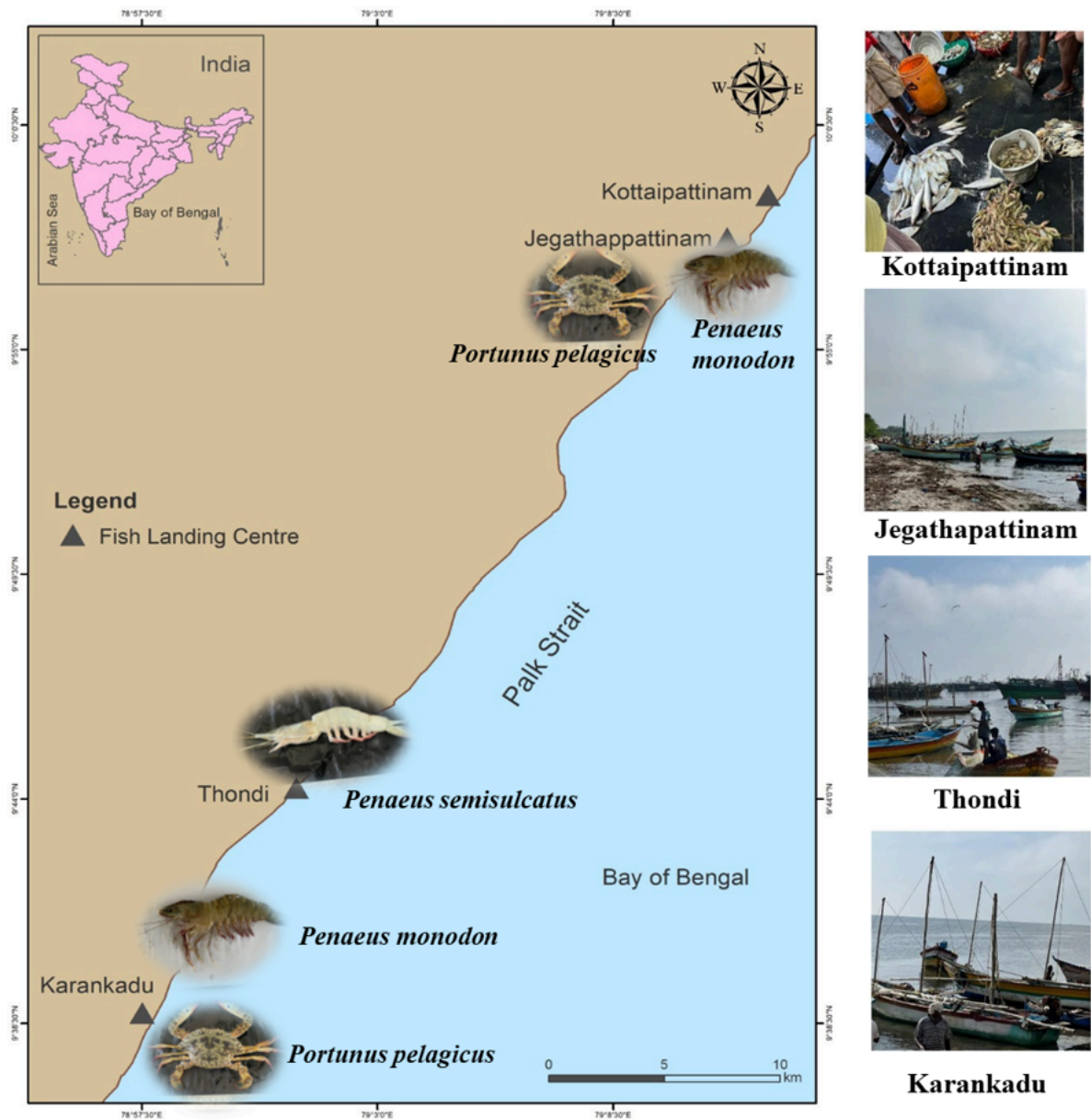


Figure 1

Sample collection at the landing centre in the Palk Bay Strait, Southeast coast of India.

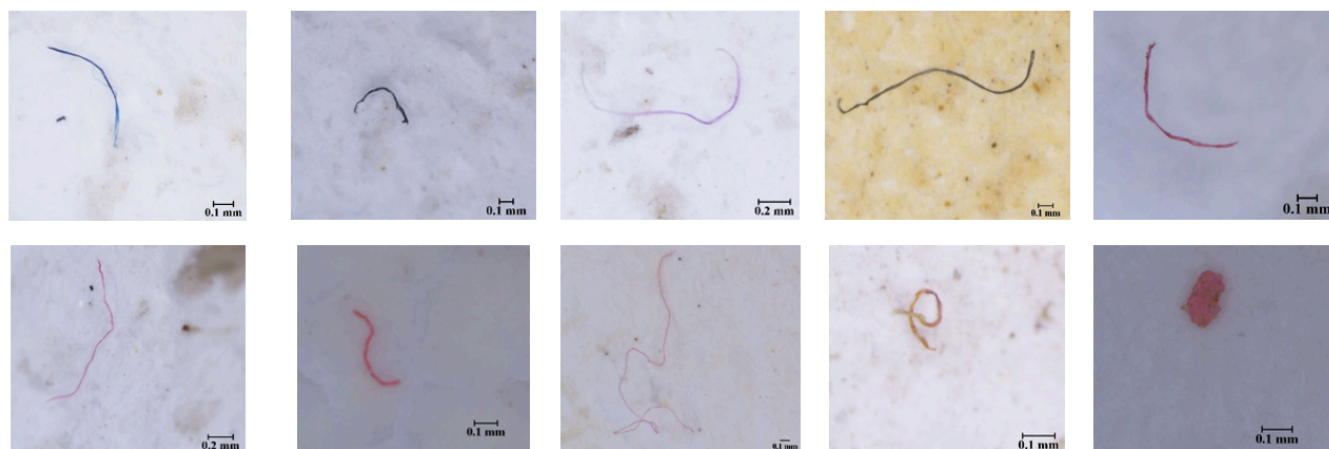


Figure 2
Stereomicrograph of MP from the gut/tissue (*Peneaus semisulcatus*, *P. monodon*, and *Portunus pelagicus*) of a commercially important crustacean from the Palk Strait (0.1–0.2 mm scale bar).

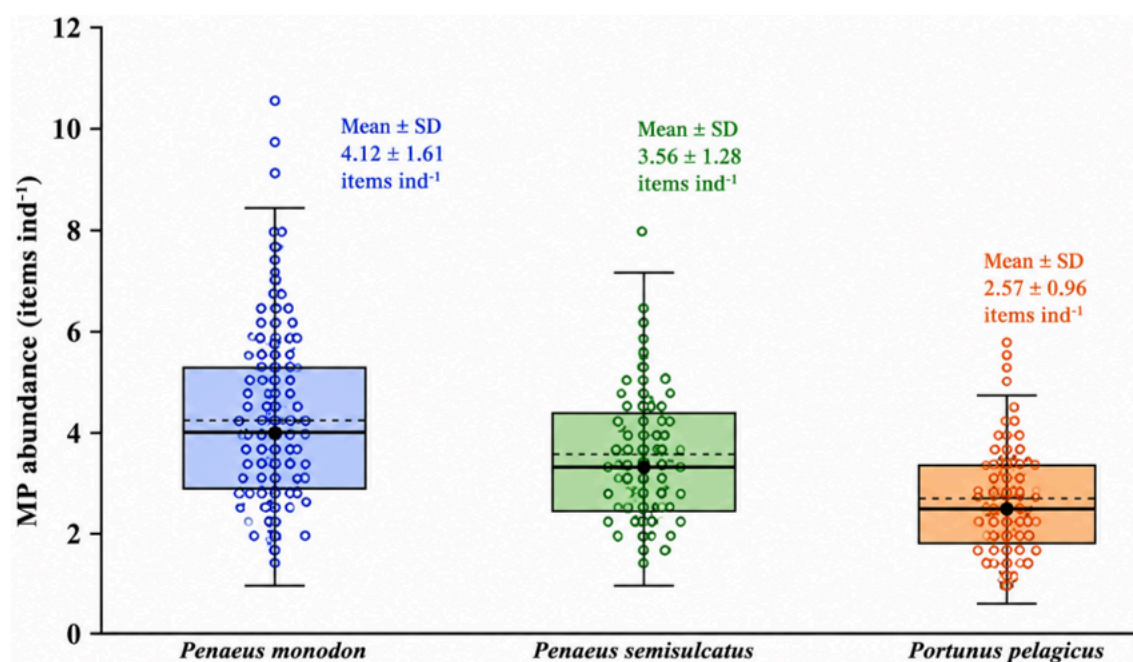


Figure 3
Box plots showing the MP abundance distribution in *Peneaus monodon*, *P. semisulcatus*, and *Portunus pelagicus* from the Southeast coast of India

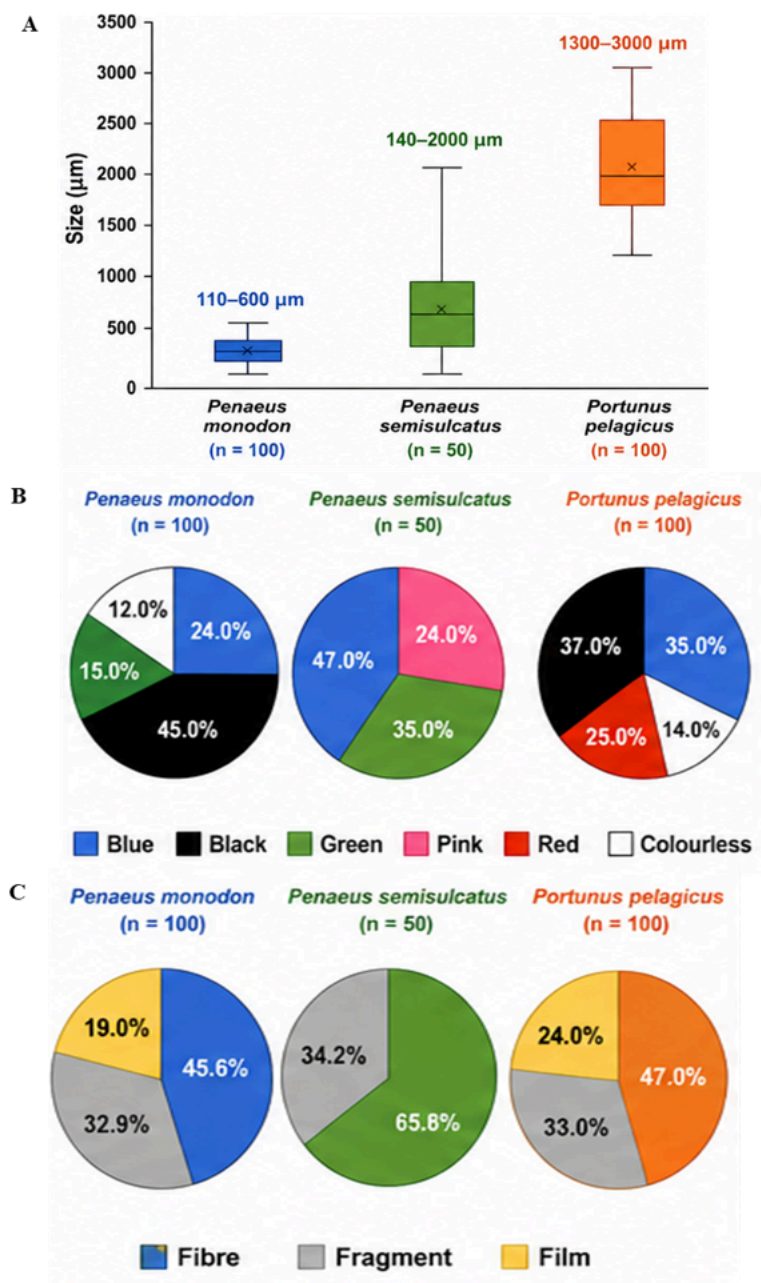


Figure 4

Characteristics of MPs (A) sizes, (B) colour, and (C) Shapes in *Penaeus monodon*, *P. semisulcatus*, and *Portunus pelagicus* from the Southeast coast of India

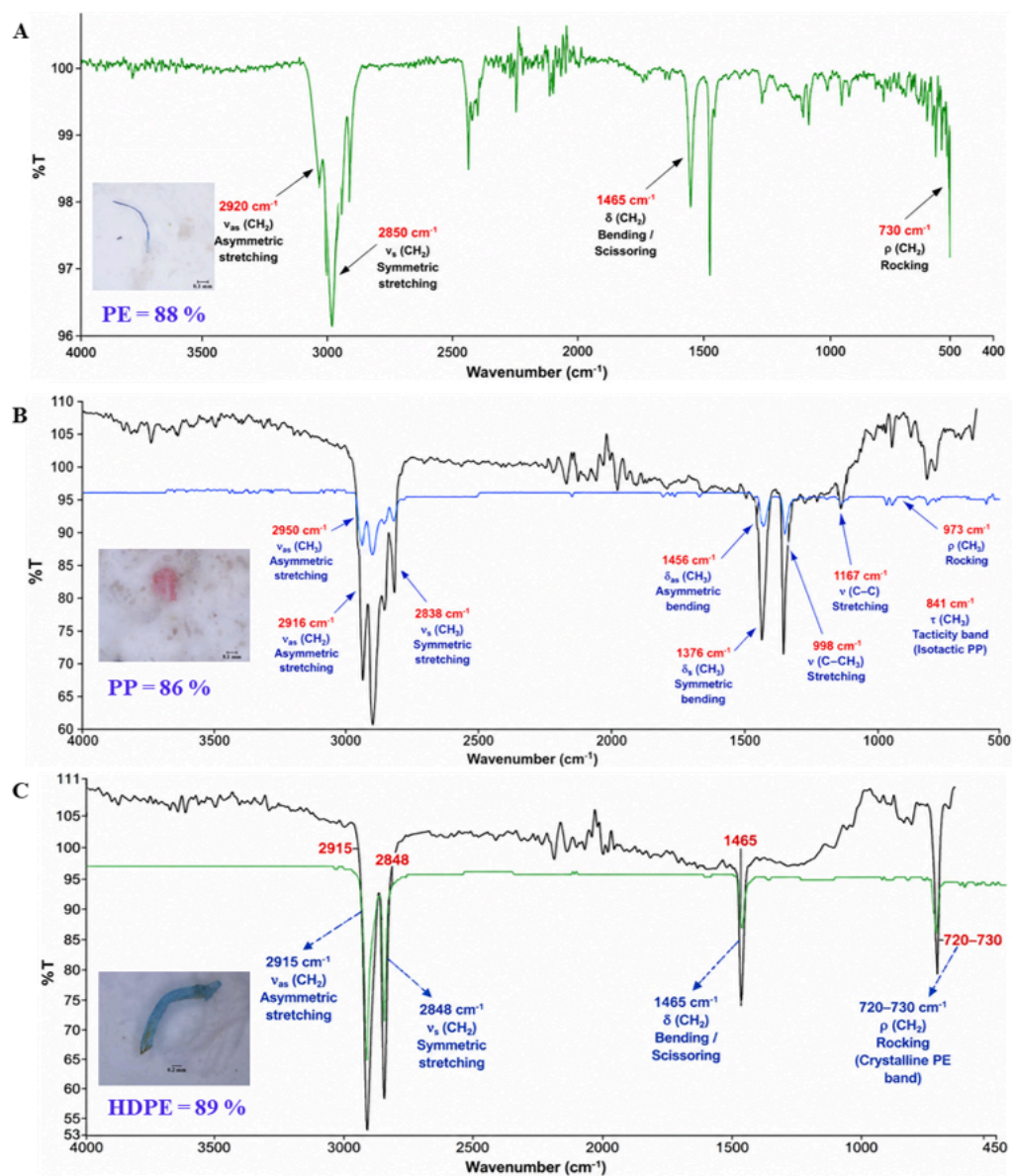


Figure 5

Representative FTIR-ATR spectra of MPs identified as (A) Polyethylene (PE), (B) Polypropylene (PP), and (C) High-density polyethylene (HDPE).

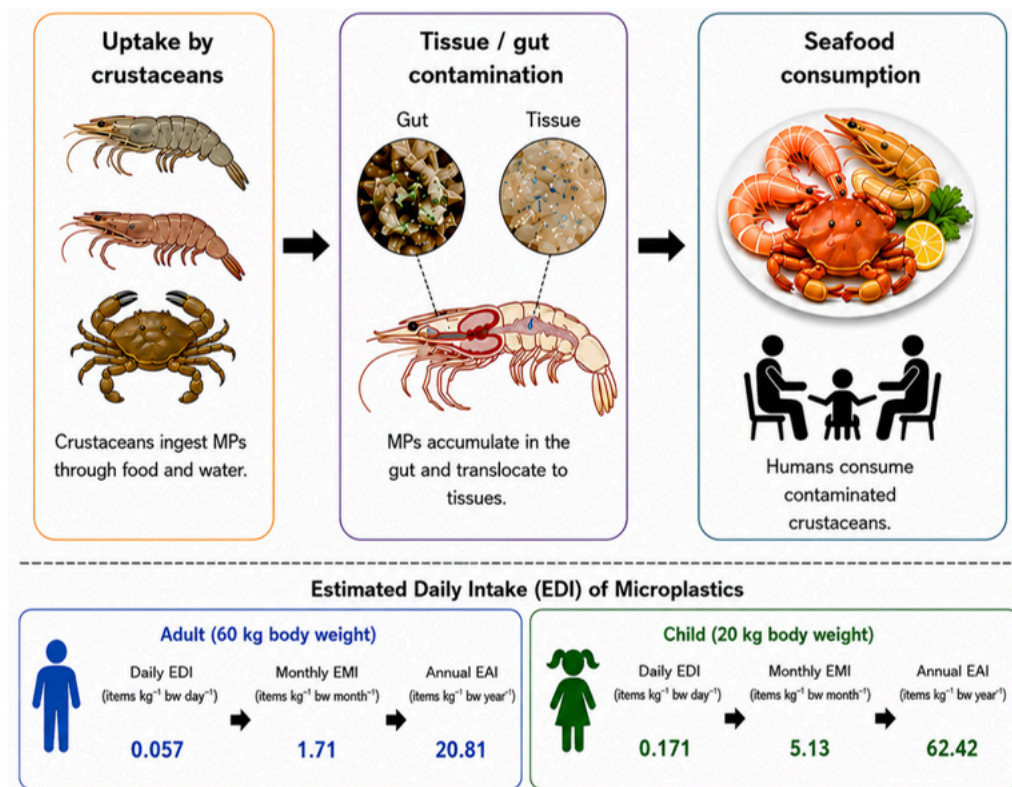


Figure 6

Estimated daily (EDI), monthly (EMI), and annual intake (EAI) of MPs through crustacean consumption for adults and children.