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First report of plastic and non-plastic microparticles in stomach of slandertail lanternshark and shortspine spurdog from the edge of East China Sea

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ABSTRACT

This study investigates the presence of plastic and non-plastic microparticles in the gastrointestinal tracts of two deep-sea sharks, *Etmopterus molleri* ($n = 118$) and *Squalus mitsukurii* ($n = 6$), bycatch from the East China Sea continental shelf. We found a total of 117 microparticles, predominantly fibres (67.52 %), with blue (31.62 %) and black (23.94 %) being the most prevalent colours. *E. molleri* contained 70 microparticles (0.63 ± 0.93 items/shark), 61.42 % non-plastics like viscose and cotton, while plastics included polyethylene, polyethylene terephthalate, and acrylic. Despite *S. mitsukurii's* limited sample size, the results show that it takes in a lot of microparticles (47 microparticles, 7.83 ± 2.64 items/shark), 57.44 % non-plastics (viscose, cotton, and ethyl cellulose), and 42.56 % plastics. A positive correlation between microparticle presence and total length was observed for *E. molleri*. These results provide initial data on microparticle ingestion by these species, highlighting potential ecological risks and trophic transfer implications in deep-sea ecosystems.

1. Introduction

Since the 1970s, plastic production has been on the rise to meet the increasing demands of society and industry (Carpenter and Smith Jr., 1972; Andrady and Neal, 2009). Approximately 400 million metric tons of plastic waste are produced annually, with projections indicating a significant increase in this quantity in the forthcoming decades (OECD, 2022). Due to their durability, low recycling rates, and mismanagement, a significant portion of these plastics enters in marine ecosystems (Lebreton and Andrady, 2019; Sun et al., 2022). Within the marine ecosystem, several biological and physical mechanisms break down plastic materials into microplastics (MPs) that have a diameter <5 mm (Barnes et al., 2009; Andrady, 2011), thus increasing the bioavailability of these particles in all compartments of the marine environment (Nelms et al., 2018; Botterell et al., 2019; Hartmann et al., 2019). Furthermore, non-plastic (man-made) microparticles from domestic and/or industrial textile washing contribute additional contaminants entering marine ecosystems (Habib et al., 1998; Woodall et al., 2014; Suaria et al., 2020; Weis and De Falco, 2022; Allen et al., 2024). The term non-plastic microparticles refers to particles from textiles of natural plant or animal origin (e.g. cotton and wool) and semi-synthetic microfibres derived from cellulosic sources (viscose/rayon) (Napper and Thompson, 2016; Henry et al., 2019; Savoca et al., 2019). With the current growth in consumption, the annual production of this material is projected to increase by approximately 33 %, reaching 146 million metric tons by 2030, up from 63 million metric tons in 2016 (Bartl, 2020; Textile Exchange, 2021; Gallidabino et al., 2023). As a result, microplastics and non-plastics microparticles are among the most found items in marine environments, from the surface layers to the seafloor (Barrows et al., 2018; Pereira et al., 2020; Suaria et al., 2020).

MPs have been found to be ingested by a wide range of marine taxa at various trophic levels, from zooplankton to megafauna (Remy et al., 2015; Lusher et al., 2016; Jamieson et al., 2019; Vecchi et al., 2021; Bottari et al., 2022; Mancuso et al., 2022; Alfonso et al., 2023) This underscores the importance of considering the probability of coexistence between organisms and microparticles (plastic and/non-plastics) in their natural habitats (Botterell et al., 2019). Plastic materials and non-plastic items from the textile sector are treated with similar

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chemical dye processes, which are usually toxic and susceptible to accumulate in the environment (O'neill et al., 1999; Ceretta et al., 2021). Ingestion of these microparticles and associated additives (e.g., flame retardants, plasticizers, UV stabilizers, and antioxidants), on the one hand, and sorption of chemicals from the surrounding marine environment, on the other hand (e.g., hydrophobic organic chemicals (HOCs)), including persistent organic pollutants (POPs), can have adverse effects on aquatic animals at different life stages and trophic levels (Rochman et al., 2013; Ma et al., 2020; Fauser et al., 2022). During early life stages, MPs may disrupt larval growth and survival, damage physiological and immune systems in low trophic organisms (Le Bihanic et al., 2020; Cormier et al., 2021). In more advanced stages, they can reduce energy reserves, affect feeding and reproduction, and impair swimming abilities (Bhuyan, 2022; Nabi et al., 2022). Meanwhile, non-plastic microparticles potentially lead to an underestimation of their potential threat due to the poorly documented ingestion of these microparticles by marine organisms in previous studies (Lusher et al., 2013; Barrows et al., 2018; Savoca et al., 2021).

While fish have been thoroughly examined and used as a valid proxy for detecting the presence of microplastics in marine biota (Scacco et al., 2022), there is a lack of knowledge regarding shark species that may ingest microplastics. Sharks are one of the most threatened groups of marine animals, as high exploitation rates coupled with low resilience to fishing pressure have resulted in population declines worldwide (Lucifora et al., 2011; Dulvy et al., 2014; Bottari et al., 2022). Although research had indicated that sharks are sensitive to anthropogenic pollution (Stelfox et al., 2016; Bernardini et al., 2018; Pedà et al., 2020; Morgan et al., 2021; Huang et al., 2022), their global exposure to both plastic and non-plastic microparticles remains understudied, especially for the deep-sea species (Valente et al., 2019; Capillo et al., 2020; Kibria et al., 2022; Lu et al., 2024). Deep-sea sharks are considered important predators in *meso* and bathy pelagic ecosystem (Heupel et al., 2014; Churchill et al., 2015). Existing research has shown that deep-sea sharks in several oceans across the world have been observed consuming microplastics (Valente et al., 2019; Parton et al., 2020). Moreover, studies have demonstrated that small deep-sea sharks are an important prey resource for higher trophic level sharks, such as the kitefin shark (*Dalatias licha*) which selectively preys on the velvet belly lantern shark (*Etmopterus spinax*) and the blackmouth catshark (*Galeus melastomus*) (Navarro et al., 2014). The presence and intake of plastic and non-plastic microparticles by organisms in global oceanic ecosystems give rise to an issue that has significant implications for marine food webs and is likely to impact deep-sea shark populations (Valente et al., 2019; Parton et al., 2020; Janardhanam et al., 2022). However, research on the impact of microplastics pollution on deep-sea sharks is limited, nevertheless, available research suggests that deep waters constitute an important sink for microplastics (Taylor et al., 2016; Jamieson et al., 2019; Kane et al., 2020).

The East China Sea (ECS) is China's most important fishing ground, providing nearly 40 % of the national's overall coastal fishery production (Zhang et al., 2016; Wang et al., 2022). Due to its adjacency to economically developed regions, the ECS is also considered a hotspot for microplastics research (Jambeck et al., 2015; Sun et al., 2018). Notably, recent studies reveal a >50 % surge in the concentration of microplastic particles within the ECS, escalating from 4137.3 n/m^3 in 2014 to over 10,000 n/m^3 in 2019 (Zhao et al., 2014; Luo et al., 2019). The major source of this pollution is attributed to horizontal transport through the surface waters of the estuarine system of the Yangtze River (Sun et al., 2022). Moreover, the river's proximity to major urban and manufacturing centers significantly amplifies the input of microparticles (Zhang et al., 2021a, 2021b; Sun et al., 2022). As research increasingly addresses the interaction between microplastics and marine biota in the ECS (Sun et al., 2018; Zhang et al., 2019a, 2019b, 2021a, 2021b; Wu et al., 2020), deep-sea sharks have received little attention despite their ecological significance.

Here, we provide novel data on the ingestion of non-plastic and plastics microparticles by two deep-sea sharks caught as bycatch in ECS bottom trawls: the slendertail lantern shark (*Etmopterus molleri*) and shortspine spurdog (*Squalus mitsukurii*). These species are listed as "Data Deficient" and "Endangered" on the International Union for Conservation of Nature (IUCN) Red List, respectively (Kyne et al., 2015; Finucci et al., 2020). The goals of our study are: (1) to provide quantitative data on the ingestion of non-plastic and plastics microparticles by *E. molleri* and *S. mitsukurii*; (2) to investigate the potential intraspecific variation between microparticle ingestion levels and individual length, and (3) to discuss the potential implications of plastic and non-plastic microparticles ingestion by small deep-sea sharks on marine food webs.

2. Materials and methods

2.1. Study area and sampling

The sampling area is located at the northern boundary of the continental shelf in the ECS. Complex hydrodynamic forces active in the area mobilize and disperse materials throughout the water column, mainly through currents such the Yellow Sea Coastal Current (YSCC), Zhe-Min coastal current (ZMCC), Taiwan warm current (TWC), and Changjiang River Plume (CRP). These currents significantly influence ECS surface water circulation during summer (Atsuhiko Isobe, 2008; Liu et al., 2021).

The samples collected were bycatch from the commercial bottom trawl fishing. The fishing nets used had a 40 mm mesh opening and were primarily used to catch demersal species between 200 and 300 m deep. At three locations, 118 specimens of *Etmopterus molleri* and 6 specimens of *Squalus mitsukurii* were collected from January to April 2023 (Fig. 1), labelled and frozen until laboratory analysis. In the laboratory after defrosting, sand and other large objects were removed from the skin by washing it in distilled water and morphometric parameters such as the total length (TL), total weight (TW), and maturity stage. Maturity was assessed by macroscopic examination on both males (based on claspers) and females (based on the presence of ovaries and uteri) using the maturity scale for aplacental and placental viviparous sharks Stehmann (2002). The specimens were then classified according three class size ([100 mm–200 mm] = juvenile; [200 mm–300 mm] = subadult; ≥300 mm = adult).

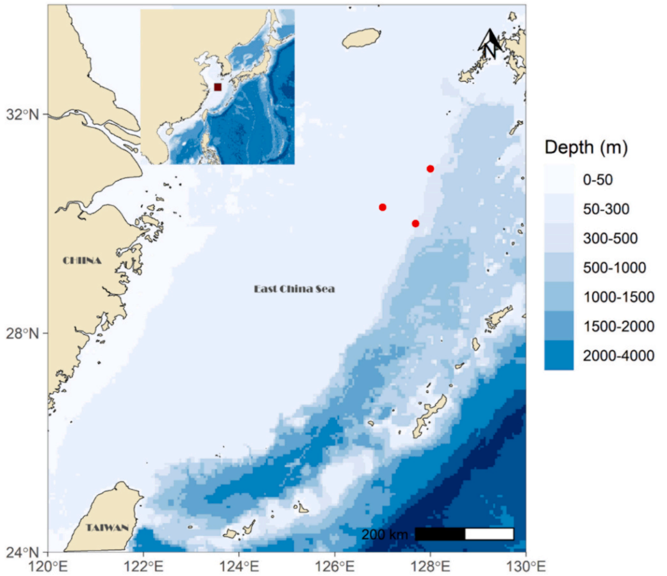

Fig. 1. Trawl locations in the ECS continental shelf, red dots represent the sampling sites. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.2. Isolation, observation, and identification of plastic and non-plastic microparticles

For the chemical digestion, we adopted a modified version to the method of previous studies (Avio et al., 2015; Kühn et al., 2017). Each fish sample was dissected on a metal table using scissors, forceps, and scalpels. The entire gastrointestinal tract (GT) was removed and placed in petri dish to determine the wet weight. Then samples were transferred into 250–500 ml conical flasks, and immediately covered with aluminium foil to avoid contamination. Alkaline potassium solution 10 % (KOH) was added to each flask in the proportion of 1 g/20v (1 g of GT/20 ml of 10 % KOH), and the mixture placed in an oscillation incubator at 60 °C with 144 rpm for 24 h.

After incubation, the same volume of saturated NaCl solution (1.2 g.ml^{-1}) was added, and the resulting mixture was homogenised and allow to rest for five hours. The solution was filtered through a 5 μm pore size, 47 mm diameter cellulose nitrate filter (Whatman AE98) with a vacuum pump. This process was repeated three times to increase the rate of microparticles recovery. The filters are then placed separately in Petri dishes with lids for microscopic observation. The filters were observed under stereomicroscope (SZX2-FOF, Olympus) couplet with a digital camera (UTVO.63XC, Olympus). Each suspected microparticle was photographed, colour and shape recorded and then the maximum length was measured using ImageJ software.

All items suspected to be microfibres were chemically analysed using a Microscopy coupled with micro-Fourier transform infrared spectroscopy (μFT-IR, Nicolet iN10 Mx Infrared Microscope in OMNIC Picta, ThermoFisher Scientific). Each particle item's FTIR spectrum was recorded between 4000 and 500 cm^{-1} at a resolution of 8 cm^{-1} with a collection time of 3 s and 16 scans. Each spectrum was automatically baseline corrected before being compared to the Hummel Polymer Sample Library and Polymer Laminate Films OMNIC standard spectra libraries (Jabeen et al., 2017) and only matches with a score of 70 % or more were accepted according to Lusher et al. (2013). A blank filter was left open to the air to control contamination and was checked immediately after the samples were observed.

2.3. Contamination control

Work areas were cleaned with filtered (20 μm) industrial methylated spirit (IMS, 99 %). To prevent airborne contamination, only glass and metallic materials were used during laboratory analysis; all apparatus (dissection tools and glassware) were rinsed three times with ultrapure water (Milli-Q water) and wrapped in aluminium foil prior to analysis and between samples and all workstations were cleaned with filtered industrial methylated spirit (IMS, 99 %). Ultrapure water (Milli-Q water) was used to prepare a 10 % potassium hydroxide and NaCl solution (1.2 g.ml^{-1}), which was stored in glass bottles that had been rinsed three times (Lusher et al., 2015). Clean cotton laboratory coat and non-sterile, single-use gloves were used for all laboratory work. During digestion procedures, three procedure blanks were also analysed without samples in parallel with digestion solution samples, to detect any ambient microplastic contamination from the equipment and the laboratory. No microparticles was found in the blank controls.

2.4. Statistical analysis

Except for 10 unsexed *E. molleri* individuals, samples were subdivided into size classes and sexed based on genital developmental stages. As microfibres count data were non-parametric, Kruskal-Wallis tests were conducted to examine significant variations in contaminating particle concentrations across species. After identifying significant interspecific differences, samples underwent individualized examinations. A generalized linear model (GLM) – negative binomial for *E. molleri* – was used to investigate the influence of sex and individual length on estimated ingested fibre counts (p-value < 0.05). Initial models included individual lengths, weights, and sex; non-significant factors like sex and weight were removed (**Supplementary Material S1**). For *S. mitsukurii*, a generalized additive model (GAM) with Gaussian distribution was used, with cubic regression splines (bs = cr) and maximum degrees of freedom (k = 3) to limit flexibility given the limited data. Models were compared via Akaike information criterion (AIC) values to determine best fit (lowest AIC). Analyses used the R packages "tidyverse", "MASS", "caret", "ggplot2", and "mgcv". Statistical analyses were performed in R 4.3.1 and RStudio 2023.06.1-524.

3. Results

3.1. Biometric parameters

A total of 124 shark samples were examined, with 118 *E. molleri* and 6 to *S. mitsukurii* specimens. The *E. molleri* samples were divided into three size categories: 100–200 mm (n = 32), 200–300 mm (n = 75), and > 300 mm (n = 11) (Table 1). Females were most prevalent across all size classes, representing 69.49 % (n = 82) of all samples. Males constituted 22.03 % (n = 26), while sex was unidentified for the remaining 8.5 % (n = 10). All *S. mitsukurii* specimens were juvenile. Among these, 83.33 % (n = 5) were male, while only one female was observed.

3.2. Plastic and non-plastics microparticles

Fourier-transform infrared (μFT-IR) analysis identified ingested particles in 49 sharks. These particles displayed three main morphologies: fibres (n = 79), fragments (n = 26), and granules (n = 12). Seven distinct colours were observed, with blue being the most predominant (31.62 %). Black was the second most common colour (23.93 %). Importantly, colour proportions differed between species (Fig. 2a and b).

The observed size distribution of the contaminant particles indicates a certain degree of uniformity across shapes, with sizes ranging from 0.1 mm (fragment) to 4.49 mm (fibre), and an average size of 1.21 ± 0.96 mm (Fig. 3a and b). Approximately 75 % of fragments and granules exhibited dimensions smaller than 0.5 mm. In contrast, over 50 % of observed fibres had sizes exceeding 1 mm. It is noteworthy to mention that the granules discovered were composed exclusively of ethyl cellulose, a specific natural polymer.

3.3. Differences between species, body length and microparticles ingestion

The Kruskal-Wallis test revealed a significant disparity in particles

Table 1
Summary of the morphometric characters of *E. molleri* and *S. mitsukurii*. Class size Cs (mm), n = number of individuals sampled, sex ratio (M = Male, F = Female, na = Unidentified), total length TL (mm), total weight TW (g), number of microparticles ingested Ps, indication of number of individuals showing ingestion in between brackets.

Species	Cs (mm)	n	Sex	TL (mm)	TW (g)	Ps (n)	Ps/ shark
			(M/F/na)	Mean ± SD	Mean ± SD		Mean ± SD
E. molleri	[100–200]	32	1/22/9	171.9 ± 19.6	19.23 ± 6.24	16 (8)	0.52 ± 1.03
	[200–300]	75	23/51/1	256.9 ± 27.9	66.53 ± 24.02	44 (28)	0.59 ± 0.92
	[300–388]	11	2/9/0	324.9 ± 23.4	138.69 ± 38.83	10 (7)	0.91 ± 0.94
S. mitsukurii	[18–24]	6	5/1/0	204.3 ± 21.3	146.12 ± 29.87	47 (6)	7.83 ± 264

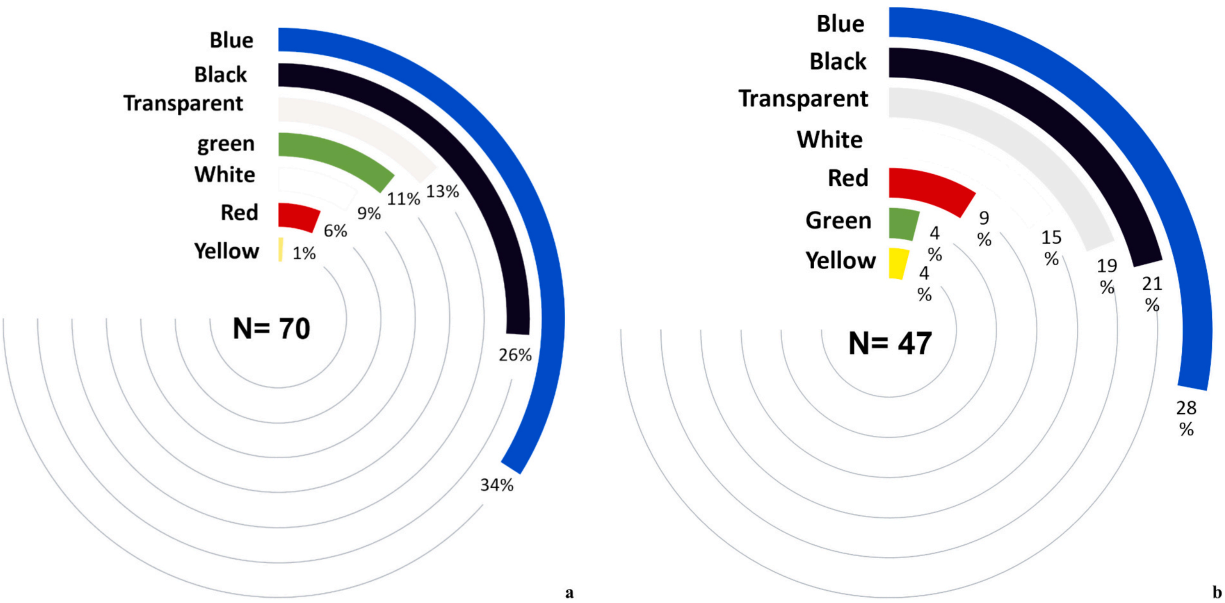

Fig. 2. Colour composition of ingested microfibres observed in the gastrointestinal tracts of (a) *Etmopterus molleri*, (b) *Squalus mitsukurii*; N = total identified fibre.

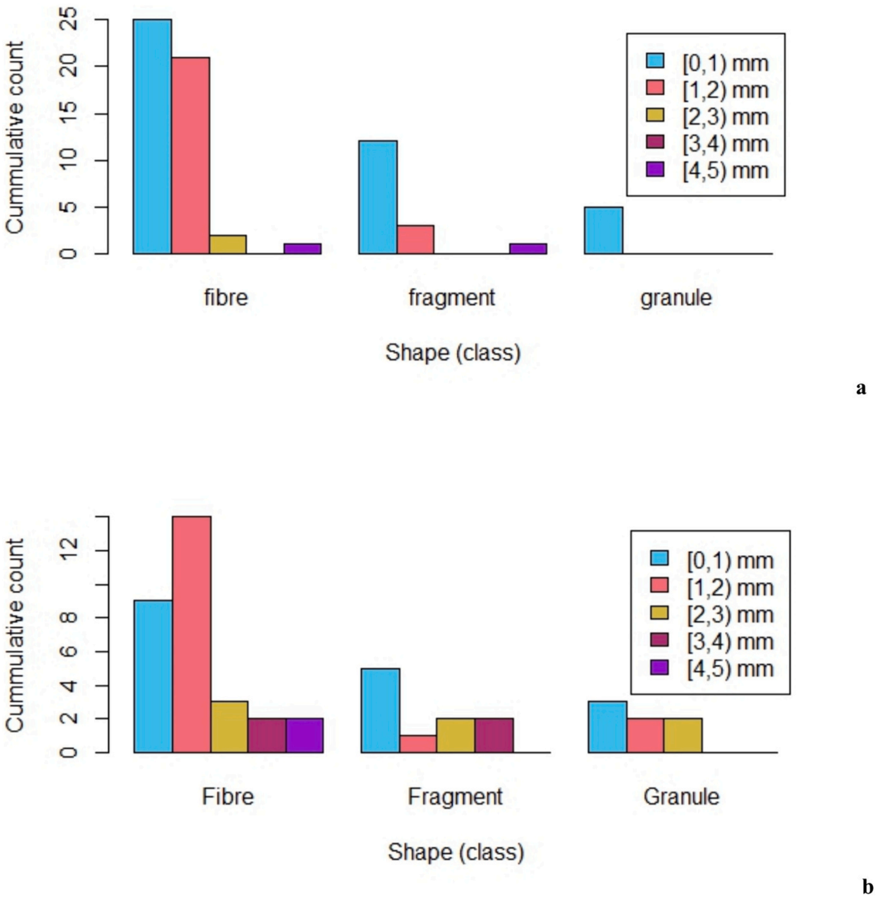

Fig. 3. Shape and fibre length distribution found in (a) *E. molleri* and (b) *S. mitsukurii.*

occurrence between species ($\chi^2 = 99{,}025$, df = 1, $p = 0.0016$). For *E. molleri,* negative binomial (GLM) analysis revealed a significant positive relationship between shark body length and estimated ingested microparticles number ($P = 0.013$) (Table 1; **Supplementary table S2, S3**). No statistically significant sex difference was observed after excluding unidentified individuals ($P > 0.05$). For *S. mitsukurii*, the generalized additive model (GAM) yielded insufficient evidence to infer the effect of individual length ($P = 0.833$) or weight ($P = 0.323$) on microparticles ingestion (**Supplementary Table 4**). Contaminating particles were detected in all 6 specimens of *S. mitsukurii* ($n = 47$). The highest number ($n = 13$) occurring in 182.3 mm juvenile. While *E. molleri* exhibiting 70 total microparticles identified, with a maximum of 4 particles in a 298.5 mm male.

3.4. Chemical composition of microparticles

Of 196 total particles examined, 117 microfibers were identified via distinct wave patterns in Fourier transform infrared (FTIR) spectra. Microparticles were categorized as plastics (synthetic fibres) and non-plastic microfibres comprised of semi-synthetic and natural polymers. Most microparticles in both *E. molleri* (45.71 %) and *S. mitsukurii* (42.55 %) were non-plastics, largely viscose (37.14 % and 29.79 %, respectively) and ethyl cellulose (7.14 % and 12.77 %, respectively). Microplastics constituted 38.57 % and 42.55 % of microfibers in *E. molleri* and *S. mitsukurii*, respectively, primarily polyester, polyethylene terephthalate, polyethylene, and polystyrene. Natural cotton fibres accounted for 15 % of all identified microfibers. It is noteworthy that these two microparticle types have an uneven distribution in relation to coloration. In the case of *E. molleri*, coloration was present in all microplastic particles, while only 25.58 % of non-plastic particles showed coloration. In contrast, *S. mitsukurii* showed coloration in 20 % of microplastics and 18.52 % of non-plastic microparticles (Figs. 4 and 5; **Supplementary Table S5**).

4. Discussion

The issue of microplastic contamination in aquatic ecosystems has garnered significant interest from the scientific community. Several studies have demonstrated instances of marine animals consuming microplastics in various depths of the ocean, spanning from shallow waters to the abyss (Lusher et al., 2013; Sun et al., 2018; Jamieson et al., 2019). However, limited research has been directed towards assessing the presence of this pollution in small deep-water sharks (Valente et al., 2019; Parton et al., 2020). In this study, we provide the initial documentation in the ECS of the consumption of plastic and non-plastic microparticles by two mesopredator sharks, *E. molleri* and *S. mitsukurii*.

4.1. Contaminating particle characteristics

The identification of plastic and non-plastic microparticles in the gastrointestinal tracts of 49 sharks highlights the extent of ingestion by these apex predators, shedding light on the potential consequences for marine ecosystems. The variety of particle morphologies observed, such as fibres, fragments, and granules, suggests diverse sources of contamination, ranging from larger plastic debris breakdown to direct release of microplastics. These findings align with previous studies documenting microparticles ingestion in various marine organisms (Rochman et al., 2013; Barrows et al., 2018). Ingestion rate of *E. molleri* and *S. mitsukurii* contrast with those observed in small demersal sharks (*G. melastomus)* in the Mediterranean (16.80 %, Alomar and Deudero, 2017), South-west coast of the United Kingdom (6.5 %, Morgan et al., 2021), and North-east Atlantic (67 %, Parton et al., 2020) on four demersal sharks, but are similar to rates reported in Eastern Pacific Ocean blue sharks (39.1 %, Huang et al., 2022).

The dyes used to colour microplastics, especially the predominant blue and black fibres in our samples, raise concerns about their potential toxicity. Several studies have highlighted the fish's tendency to preferentially ingest coloured fibres, especially black ones (Rochman et al., 2013; Savoca et al., 2019; McGoran et al., 2021). Despite the well-documented ecotoxicological impacts of microplastics, the specific effects of synthetic dyes used in their manufacturing remain underexplored (Du et al., 2022). It is known that some of these dyes, like azo compounds, phthalates, or heavy metals, can be harmful and can mess up hormone systems, damage DNA, or build up in tissues (Zimmermann et al., 2019; Malafaia et al., 2022). Ingestion by marine organisms could have negative effects on the marine environment and biological components (Du et al., 2022; You et al., 2021). The predominance of blue and black colours among the identified particles indicates potential sources such as synthetic textiles, fishing gears, and industrial materials. Interestingly, variations in colour proportions between shark species suggest potential differences in feeding habits or habitat preferences, influencing their exposure to specific types of microparticles (Taylor et al., 2016; Morgan et al., 2021; Okamoto et al., 2022). Also, the hypothesis of microplastics ingestion by confusion with the colours of natural prey put forward by several authors (Lusher et al., 2015; Ory et al., 2017; Zhang et al., 2019a, 2019b) does not seem to explain the predominance of the colours found. Indeed, at those depths where light is scarce (twilight zone), predators feed on bioluminescent prey and/or on a hard exoskeleton that looks more like hard plastics (Alomar and Deudero, 2017; Valente et al., 2019). The trophic transfer ingestion pathway, on the other hand, could explain this evidence. Trophic transfer of microplastics has been observed in various marine animals, including plankton networks (Setälä et al., 2014; Wu et al., 2020; Alfonso et al., 2023) and more complex networks such as tuna and large pelagic species (Zhang et al., 2019a, 2019b; Justino et al., 2023; Lu et al., 2024). The majority of them were >1 mm in length, whereas the fragments and granules were concentrated below 0.5 mm. This distribution conforms with previous research on microplastics consumed by

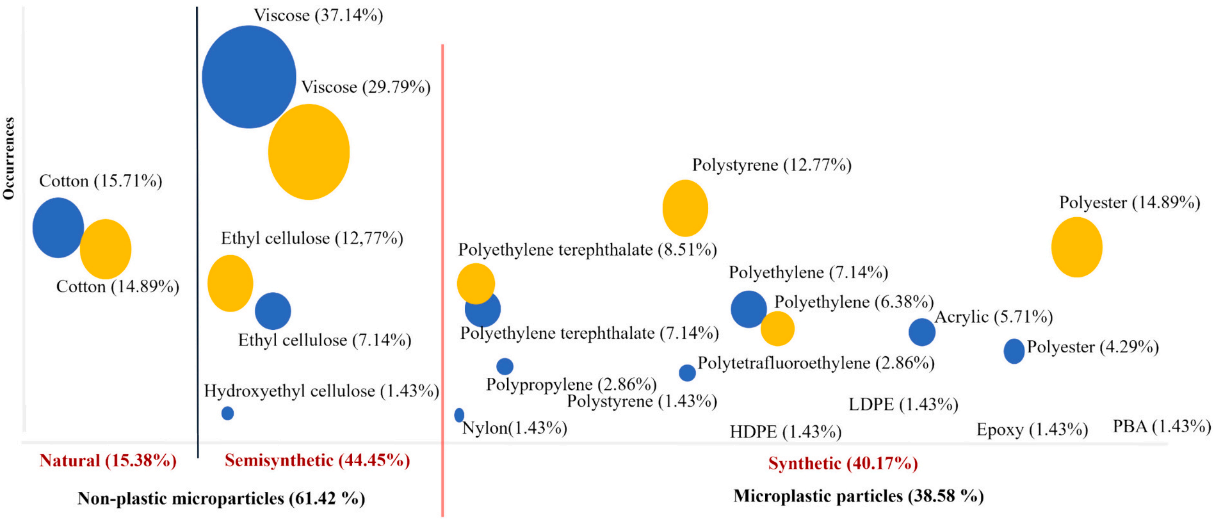

Fig. 4. Distribution of polymers found in both deep-sea sharks (yellow dot) *E. molleri* and (blue dot) *S. mitsukurii*. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

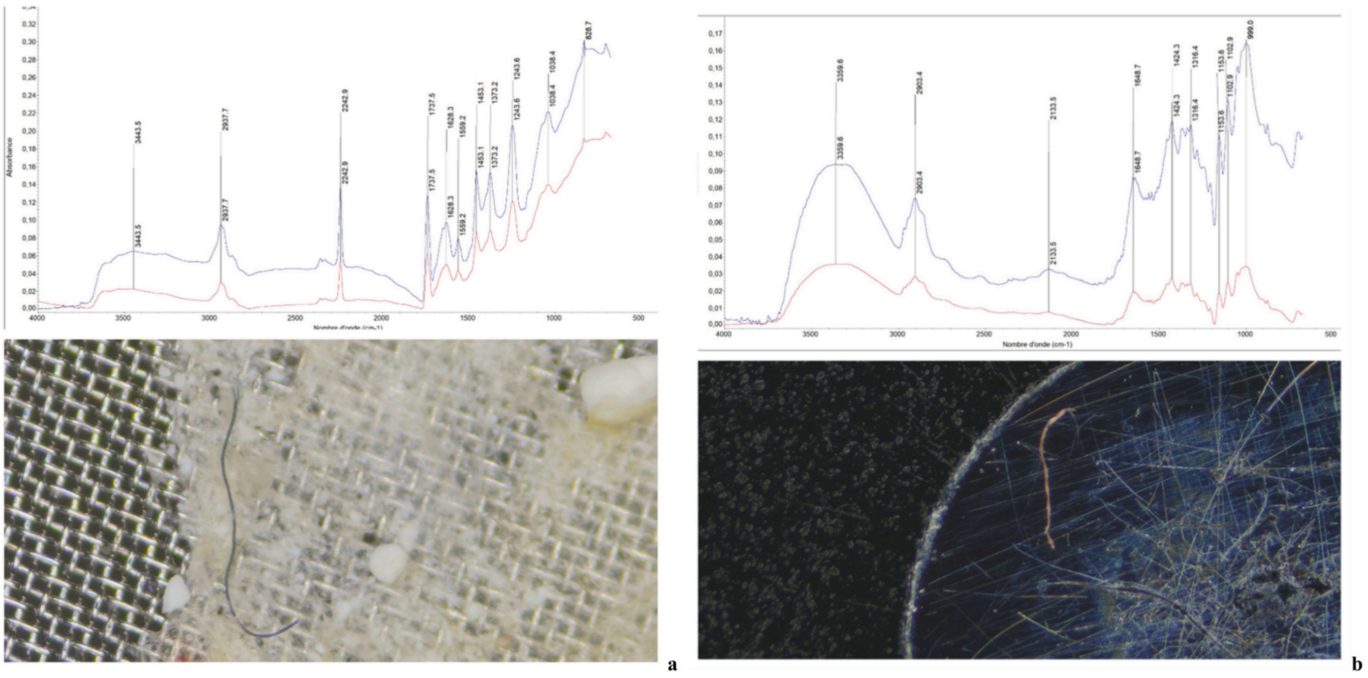

Fig. 5. Spectra of isolated plastic (a) acrylic and non-plastic microparticles (b) cotton found in the gastrointestinal tracts.

fish in the mesopelagic water layer (Lusher et al., 2016; Markic et al., 2020).

4.2. Microfibres polymer composition

The polymer composition of microparticles ingested by *E. molleri* and *S. mitsukurii* offers valuable insights into the sources and potential impacts of anthropogenic pollution in these remote marine environments. Fourier transform infrared (μFTIR) spectroscopy analysis revealed a diverse array of microfibers, encompassing both plastics and non-plastic materials. Interestingly, a significant proportion of ingested microparticles were identified as non-plastics, consisting mainly of viscose and ethyl cellulose. This finding suggests a complex interplay between natural and synthetic polymers in the marine environment, possibly originating from diverse sources such as textiles, wastewater effluents, and coastal runoff (Botterell et al., 2019; Savoca et al., 2021). Viscose and ethyl cellulose constitute major proportions of the observed non-plastic fraction found in our samples (37.14 % and 29.79 %, respectively for *molleri* and *mitsukurii*) and Similar results have been highlighted how viscose contributes to fish microfibres in the ECS (64.16 %) Wu et al. (2020), (66.8 %) Yu et al. (2022), in the south Atlantic (51.1 %) McGoran et al. (2021), Northeastern Pacific (70 %) Lu et al. (2024) and the southwestern Atlantic (77 %) Macieira et al. (2021). As cellulose-based materials, their discovery merits concern regarding the underestimated role of fishing industry waste in introducing biodegradable microfibers into marine food webs (Parton et al., 2020; Kartal and Sarıışık, 2022).

Among identified microplastics, polyester and polyethylene terephthalate dominate, reflecting their mass production for textile and packaging applications (Barrows et al., 2018). The variation in polymer composition discovered in the study is closely related to fishing and human activities in the marine and coastal environments (Xiong et al., 2022). According to Sun et al. (2022) microplastics dispersion model in the ECS, terrestrial sources account for the majority of microplastic contamination, including the Changjiang River estuary system, Hangzhou Bay, and the coast of Nantong City. These locations are home to around 30 % of the total Chinese population and house a number of textile industries. Widespread cotton reflects terrestrial and maritime sources undergoing environmental degradation (Yang et al., 2019). While synthetic microplastics often dominate discussions on marine pollution, the inclusion of natural fibres in deep-sea shark diets suggests a broader range of sources and transport mechanisms for microfibers in marine environments. Understanding the relative contributions of natural and semisynthetic microfibers to overall microplastic pollution is crucial for developing effective mitigation strategies and policies to protect marine ecosystems and biodiversity (Lusher et al., 2016; Cormier et al., 2021).

Nevertheless, this polymer composition reflects the patterns of microparticles found in all ocean basins (Suaria et al., 2020). The identification of the polymers gives substantial insight on the origin and fate of microplastics in deep sea ecosystems. It can help to understand the ecotoxicological hazards that face marine life when coupled with an analysis of additives and associated pollutants.

4.3. Differences among species and the effect of size

Our findings suggest that contaminating particle ingestion rates differ between the two species. In comparison to *E. molleri* (0.59 particles/shark), *S. mitsukurii* had a substantially larger charge of ingested particles (7.83 particles/shark); the conclusion drawn about *S. mitsukurii* must be considered relative due to the limited sample size ($n = 6$ samples). This large discrepancy about number of microfibres ingested can be explained by the two species' unique feeding habits, *S. mitsukurii* is a bottom-feeding demersal predator, whereas *E. molleri* is a benthopelagic species that feeds in open water. Microplastics tend to accumulate in sediments, increasing demersal species exposure (Woodall et al., 2014; Barrett et al., 2020), this could explain why *S. mitsukurii* has greater ingestion levels that are consistent with other demersal predatory fish, (Valente et al., 2019; Zicarelli et al., 2023). Nevertheless, the intake rates of microparticles by *E. molleri* are similar to those of other studies conducted on planctivores (0.62 ± 0.67 n/individuals) and piscivore fish (0.41 ± 0.8 n/individuals) in the ECS (Wu et al., 2020; Zhang et al., 2019a, 2019b).

Furthermore, a substantial positive connection between individual size (total length) and microfibre intake was identified in *E. molleri*. Particles were consumed in greater quantities by larger specimens (Table 1). This tendency is consistent with the fact that larger size is often associated with a more complex and diverse diet, resulting in increased microplastic exposure (Nelms et al., 2018; Parton et al., 2020; Justino et al., 2023). Unlike some previous research (Bellas et al., 2016), your study found no significant influence of sex on intake. This could indicate that males and females in each species tested had similar feeding habits.

4.4. Deep food web implications

Although preliminary, results have potentially significant implications for this vulnerable ecosystem. First, the identification of plastic and non-plastics microfibres in the gastrointestinal tracts of those *meso*-predators illustrates their potential transport via food webs. Other investigations have found these particles in probable prey such as mesopelagic fish or cephalopods (Anastasopoulou et al., 2013; Choy et al., 2019; Lusher et al., 2016). Microplastics can operate as drivers of organic and inorganic pollutants, trophic transfer is a problem because it can result in bioaccumulation in higher trophic levels (Maes et al., 2020; Huang et al., 2022; Justino et al., 2023). This increases the toxicological risk for already endangered species like *S. mitsukurii*. Furthermore, our findings suggest the connection of plastic and non-plastics microparticles circulation between pelagic, mesopelagic, and benthic habitats.

Several studies have shown that microplastics in the upper layers of the ocean can be moved vertically through the water column via physical and biological processes, and that biofouling can weigh them down (Lusher et al., 2016; Porter et al., 2018). Microplastics in benthic and abyssal habitats are likely to be consumed by a variety of animals, including demersal and benthic fish, crabs, and echinoderms (Courtene-Jones et al., 2017; Jamieson et al., 2019; Kibria et al., 2022). When eaten up, some of these organisms, including the sharks' prey, can convey ingested plastic and non-plastics microfibres to higher trophic levels, resulting to the vertical transfer of microplastics across the trophic web (Botterell et al., 2019). Finally, once expelled, microfibres can join sediments and collect in these deep habitats that constitute terminal sinks (Kane et al., 2020). A better understanding of plastic and non-plastics microfibres dissemination and accumulation processes along food webs and between marine compartments is critical for assessing ecosystemic hazards (Suaria et al., 2020).

5. Conclusion

The present study report for the first time the evidence of ingestion of plastic and non-plastic microparticles by two deep-sea sharks in the East China Sea. While microplastics constitute a significant proportion of ingested particles, non-plastic microfibers such as viscose and ethyl cellulose also substantially contribute to the overall microparticle ($>$ 55 %) burden in these meso predators. Furthermore, future study has to address the added challenge of the dyes used in their manufacture. A thorough comprehension of these concerns shall guide management and regulatory strategies for conserving the integrity of marine ecosystems, particularly in vulnerable deep-sea habitats.

CRediT authorship contribution statement

Mboglen David: Writing – original draft, Software, Methodology, Investigation, Formal analysis, Conceptualization. **Yi Gong:** Writing – review & editing, Validation, Resources, Methodology. **Zehao Guo:** Methodology, Formal analysis. **Ngo Nola Dorine:** Methodology, Formal analysis. **Yunkai Li:** Writing – review & editing, Supervision, Resources, Funding acquisition, Conceptualization.

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.

Data availability

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

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Ethics statement

We followed all applicable institutional or national guidelines for the care and use of animals. All samples in this study were dead by-catch sharks that did not engage in illegal commercial activities. This scientific research activity complies with the relevant requirements of the Wildlife Protection Law of the People's Republic of China.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2024.116531.

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