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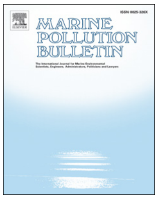

Microplastic ingestion by zooplankton in Terengganu coastal waters, southern South China Sea

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ABSTRACT

This study investigates the presence of microplastics in surface seawater and zooplankton at five different locations off the Terengganu coast in Malaysia, southern South China Sea. A total of 983 microplastic particles, with an average abundance of 3.3 particles L^{-1} were found in surface seawater. An average of one plastic particle was detected in 130 individuals from 6 groups of zooplankton. These groups include fish larvae, cyclopoid, shrimps, polychaete, calanoid and chaetognath where they ingested 0.14, 0.13, 0.01, 0.007, 0.005 and 0.003 particle per individual, respectively. Microplastics in the form of fragments are the most common type of ingested microplastics that ranged between 0.02 mm (cyclopoid) – 1.68 mm (shrimp and zoea). Contrastingly, fibers, which are identified as polyamide are the main type of microplastics that dominate in seawater.

1. Introduction

The issue of plastic pollution has intensified in recent years with various studies reporting their presence and abundance in the world's oceans. An estimated 5.25 trillion plastic particles pollute ocean surfaces (Eriksen et al., 2014), while other forms of plastic litter can widely be found contaminating coastal and deep-sea sediments (Woodall et al., 2014). However, many of these studies mainly focused on large plastic items and their impact on marine biota such as entanglement and strangulation (Lavers and Bond, 2016) but in fact, it is often overlooked that smaller plastics (microplastic, < 5 mm in diameter) pose a bigger threat. In recent years, there have been growing concerns that microplastics can have detrimental effects on aquatic life, marine ecosystems and human health (Lusher, 2015; Wright et al., 2013) such as marine wildlife dying of starvation due to ingesting high amounts of microplastics which give them the false impression of actual food.

Microplastics primarily originate from manufactured items of microscopic size (e.g., exfoliates in cosmetics products), or secondary items derived from the biological-, photo-, and/or mechanical breakdown of macroplastics. Being similar in size to natural food items and suspended organic particles, microplastics can be ingested by a variety of marine organisms (Setälä et al., 2014). In the natural ecosystem, uptake of microplastics has been recorded in a diverse array of marine organisms including fish (Lusher et al., 2017; Mattsson et al., 2015; Rochman et al., 2015), bivalves (Van Cauwenberghe and Janssen, 2014), invertebrates (Devriese et al., 2015; Welden and Cowie, 2016) and even zooplankton (Desforges et al., 2015; Kosore et al., 2018; Sun et al., 2018). These organisms can either ingest microplastics as food, whether unintentionally capturing them while filter- or deposit-feeding or mistaking them for prey when foraging, or even by ingesting organisms of lower trophic levels containing these particles, i.e. trophic transfer (GESAMP, 2015).

To further understand the risks and the potential threats of microplastic on marine organisms, a number of laboratory experiments have been performed over recent years with positive support from the scientific community as research on the matter has significantly grown, especially after 2012 (Nobre et al., 2015; Phuong et al., 2016; van Sebille et al., 2015). Of the many studies done over the recent years, toxicity studies on microplastics in invertebrates mainly reported adverse effects such as reduced feeding and energy reserve, nutritional deprivation, incorporation of microplastics into body tissue and physical damage to the digestive tract (Browne et al., 2011; Wright et al., 2013; Cole et al., 2015).

Although the effects of ingested microplastics are inconsistent (Hämer et al., 2014; Kaposi et al., 2014), there is a possibility that the results may be biased towards to a particular type of polymer (e.g. polystyrene microbeads) which are not representative of the diverse forms currently present in organisms and environment. Moreover, concentrations of microplastics used in ecotoxicological studies are generally higher than average surface water concentrations as

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summarized by Hurley et al. (2018). This is a significant concern as unrealistically high doses of microplastics exposure in experimental studies may lead to erroneous conclusions about the threat posed to marine organisms.

As one of the three mega-diversity countries in the tropical ASEAN region besides Indonesia and the Philippines, Malaysia generates a whopping 0.5–1.9 kg/capita/day of municipal solid waste (MSW) (Aja and Al-Kayiem, 2014), with plastic being the highest (24%) of the total MSW composition. As a result, Malaysia has been highlighted as the top plastic producer among other Asian countries (National Solid Waste Management Department, 2011). Nevertheless, environmental data linked to the abundance of plastic pollution in the marine environment is scanty, especially in Asia as it is one of the least studied continents in terms of microplastic contamination. In Malaysia, existing studies only concentrated on plastic pollution in sediment (Barasarathi et al., 2011; Fauziah et al., 2015; Mobilik et al., 2017; Noik and Tuah, 2015; Teuten et al., 2009) This is due to easy accessibility to collect samples. Besides that, a recent study by Khalik et al. (2018) reported that the coastal Malaysian states of Terengganu and Pahang possess 0.13 to 0.69 particles L^{-1} of microplastic distributed in surrounding seawater. Interestingly, the documented microplastics were able to be identified as six different polymers – 1) polyester 2) polystyrene 3) polyamide 4) polyvinyl chloride 5) polypropylene 6) polyethylene. There are almost no studies conducted on microplastic contamination in organisms, particularly marine organisms in Malaysia. The very limited information that exist to date are by Ibrahim et al. (2016, 2017).

Therefore, the present study aims at investigating the microplastic occurrence in zooplankton and seawater at coastal areas of Terengganu, Malaysia located in southern South China Sea. Though tiny in size, zooplankton plays a significant role in the pelagic ecosystem as the connection between primary producers and higher trophic levels, including humans. Through ingestion, zooplankton might serve a route via which microplastics enter the food web, posing a risk to secondary producers, apex predators and potentially, human health (Steer et al., 2017). This will further provide baseline data for more studies on microplastic pollution in the future, especially that on marine organisms and lay the foundation for ecological risk assessment to determine and monitor 'good environmental status' for plastic pollution in Malaysia.

2. Material and methods

2.1. Sampling and study area

The southern South China Sea (SSCS) is a semi-enclosed tropical continental shelf sea which is mainly bordered by several countries including Thailand, Cambodia and Vietnam, which covers the northern part of the continental shelf while Malaysia, Brunei and Singapore is situated south of SCSS. The study area (Terengganu coast) is a shallow shelf area (water depth less than 80 m) located on the east coast of Peninsular Malaysia. Some developments in Terengganu are located along the coast and island, where various human activities such as tourism, fishing and boating are present. This area is also highly prone to coastal erosion which is not only caused by large monsoon waves, but also by a more complicated interaction of offshore bottom bathymetry and island shelters. Coastal erosion then becomes more frequent as a result of major sea reclamation (M.-Muslim et al., 2007).

Sampling was carried out in August 2017 at five stations of different depths - three sites located at a depth ranging from 10 m to 15 m (ST 1; Pulau Karah, ST 2; Pulau Bidong, and ST 4; Pulau Redang), one site at the depth of up to 24 m (ST 3) while another was located near the beach (5 m depth, ST 5) (Fig. 1)

For zooplankton abundance and digestion, five vertical tows each were taken from subsurface water of 3 m depth by using a Norpac net (50 cm mouth diameter, 200 cm long-sock, and 60 μm mesh size) fitted with a Hydro-Bios digital flowmeter tied to the mouth opening. To conduct microplastic analysis, 60 L surface water was sampled using a calibrated steel bucket (6 L) before being filtered through a 20 μm net (30 cm mouth diameter, 55 cm long-sock) to trap microplastics. Zooplankton samples were then immediately transferred into a glass bottle and preserved with 10% formalin, while microplastic samples were cooled at 4 °C for further laboratory analysis.

2.2. Microplastics in seawater: processing and analyzing

Microplastic analysis was carried out following a method documented in Khalik et al. (2018). Samples were filtered through a Whatman Sterile Cellulose Nitrate Membrane (47 mm Ø and 0.45-μm pore size) by using vacuum filtration. All samples were then transferred into a glass petri dish after rinsing with Milli-Q water several times and covered to prevent any airborne contamination. The observation for microplastics was conducted after 24 h and identified visually according to shape under a stereomicroscope (Olympus SZX7, Japan, 3.2× - 5× magnification) equipped with a microscope eye-piece camera (Dino eye AM4023×). Microplastics identified (6–514 particles; depending on station) were collected using a stainless-steel tweezer and classified according to two different shapes - fragment or fibers. All particles were then placed in a 20 ml glass vial until further assessment. In order to prevent sample contamination, two clean petri dishes were placed on either side of the sample during filtration and visual observation. All samples bigger than 5 mm in size were discarded from the analysis.

Microplastic particles were further identified by using Fourier Transform Infrared (FTIR) spectroscopy (IRTracer-100 Fourier Transform Infrared, Shidmadzu, Japan) with Attenuated Total Reflectance (ATR) mode for polymer identification purposes. The particles were analyzed at the mid-IR range of 4000–400 cm^{-1} with 16 scans per analysis. All spectra were interpreted based on previous works by Ibrahim et al. (2017), Jung et al. (2018), Khalik et al. (2018), and Pavia et al. (2001). The detection limit of the FTIR is 100 μm.

2.3. Analysis of zooplankton abundance

The abundance of zooplankton was quantitatively analyzed using a Sedgwick-Rafter counting cell (dimensions: 50 mm × 20mm × 1mm; area: 1,000 mm^2). Each individual was examined under a compound light microscope (Olympus, SZX7 Japan, 100× magnification). A minimum of 400 individuals were counted and identified following a method developed by Johnson et al. (2012) and Richardson et al. (2013) while the classification of zooplankton trophic levels was based on Baier and Purcell (1997) and Deehr et al. (2014). Zooplankton abundance was calculated by dividing the number of each group in subsample of known volume per net by the volume of filtered seawater. Only zooplankton with a size of > 500 μm were manually selected and included in the calculation. All zooplankton were classified into six dominant groups; cyclopoids, calanoids, polychaetes, shrimps and zoea, chaetognaths and fish larvae, which accounts for over 62% of the total zooplankton abundance in the study area.

2.4. Microplastic analysis in zooplankton

All samples were sorted based on six major zooplankton groups (10–700 individuals) and placed into 20 ml scintillation glass vials for digestion analyses. However, these numbers may vary depending on the abundance of each zooplankton group at each station. The zooplankton grouped together was always of the same taxon from the same station. Each individual was isolated and placed into a cavity block (4 cm × 4 cm, 3 cm diameter), each containing 20 individuals. To ensure no impurities present, all samples were re-examined under the microscope for foreign particles and were removed using tweezers. About 17–20 μL of 65% nitric acid (HNO_3) were dropped into each cavity block to cover each zooplankton sample (Desforges et al., 2015). The blocks were covered and heated at 80 °C for 30 min. Three HNO_3

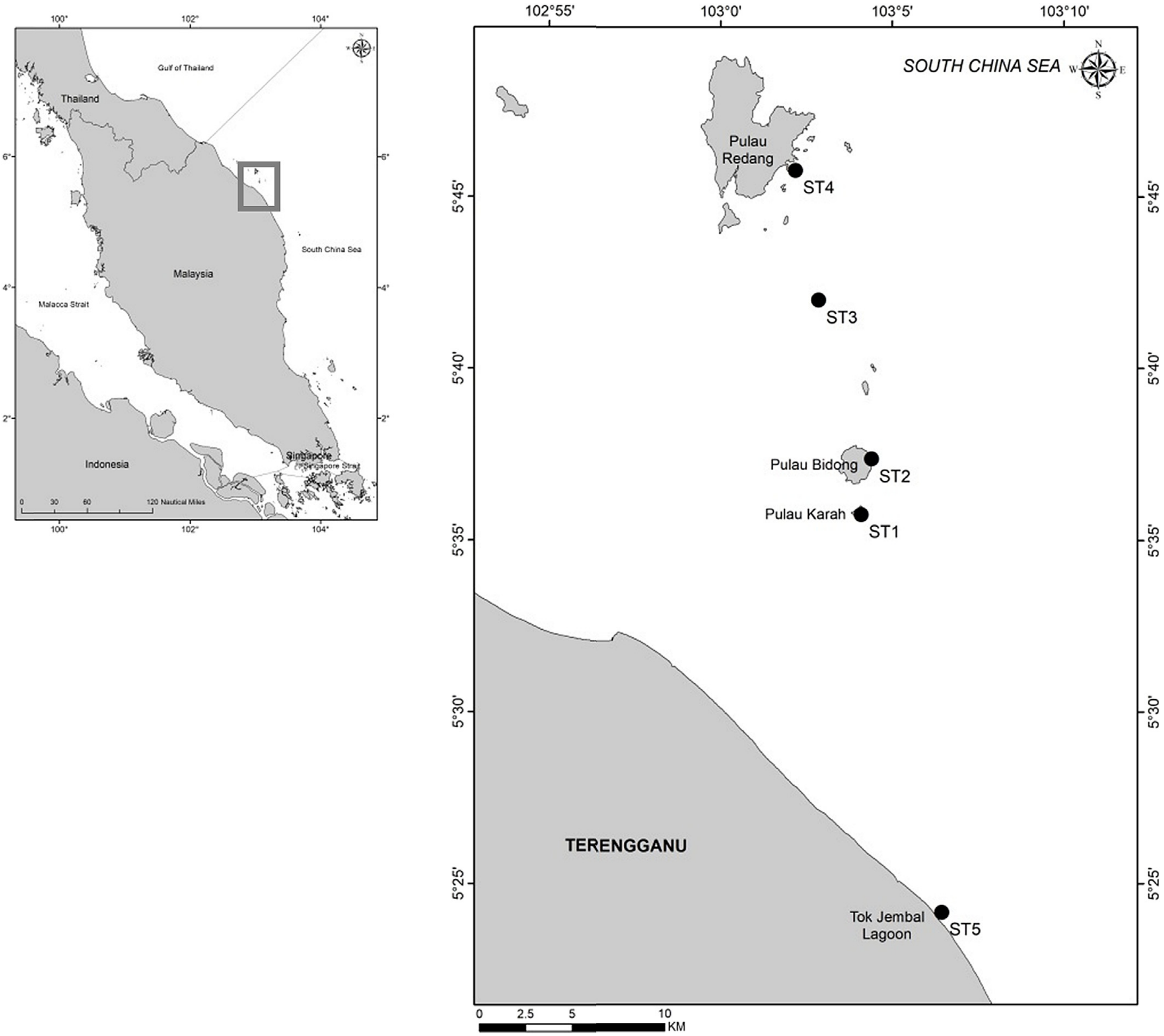

Fig. 1. Microplastics and zooplankton were collected from five different stations at Terengganu coastal water located at east coast of Peninsular Malaysia. The figure on the right is a magnified version of Terengganu.

blanks were also added to correct any potential airborne particles and prevent any contamination during the analysis. According to Desforges et al. (2015), nylon, polyethylene terephthalate, and biopolymers (e.g., acetal, polyetheretherketone) may be affected by concentrated nitric acid (Desforges et al., 2015). Thus, the results presented here is a conservative estimation of microplastic ingestion by zooplankton.

After the digestion process, the blocks were immediately examined for microplastics using a compound light microscope (Olympus, CX22 × LED, 100 × magnification). The microplastic particles found were counted and their length measured, while their shape and size were observed. All observed particles (n = 24) were removed and placed into a 20 ml glass scintillation vial containing ultrapure water. However, due to small amounts of microplastics in zooplanktons, conducting tests using the Fourier Transform Infrared (FTIR) could not be done. Alternatively, a Scanning Electron Microscope (model: JSM-6610LV) was used to identify the microplastics according to outer and internal morphological characteristics (e.g., lack of cell structure) as in Desforges et al. (2014). As a precautionary step, all tools and glassware were rinsed with ultrapure water several times to avoid contamination during sample analysis. The ingestion incidence for each zooplankton group at each station was determined by dividing the number of particles found in zooplankton by the number of digested zooplankton. To infer the potential ingestion of plastics in the water column, zooplankton samples that were collected at the same location of the microplastic samples were identified, and the microplastics abundance that was ingested per cubic meter by the predominant groups was estimated.

2.5. *Statistical analysis*

All data analysis was conducted by using SPSS software (IBM SPSS V. 20.0). Nonparametric one-way ANOVAs (Kruskal-Wallis tests) were used to compare plastic ingested of zooplankton group among the studied areas. Correlation between concentration of microplastics and size were performed with the Spearman correlation. Distribution maps of microplastic ingestion in zooplankton were created using ArcGIS

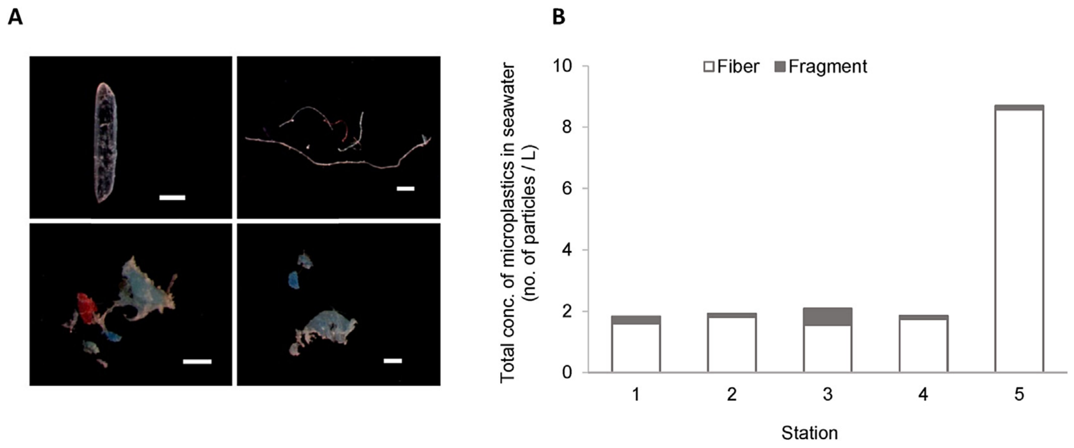

Fig. 2. A) Representative digital images of microplastic size and shape, and B) The total concentration of microplastics in surface water of the study area. [scale bar: 200 μm].

software.

3. Result

3.1. Microplastics in seawater

The majority of microplastic particles found were fibers and fragments (Fig. 2a) with fibers constituting a majority (> 70%) of the microplastics found in seawater samples. The total concentration of microplastics was greatest at ST 5 (9 particles L^{-1}), which was located nearer to the beach compared to other sites around the islands (Fig. 2b). Mean abundance ranged from 0.3 to 1.45 particles L^{-1}.

The FTIR spectra for the most abundant microplastic in all five stations showed a similar peak characteristic for polyamide polymer type albeit the slightly wet samples (ST1; Pulau Karah, Fig. 3). The compound exhibited a spectral band for medium to strong N–H stretching associated with amine group at $\nu = 3358\ \mathrm{cm}^{-1}$, followed by N–H bending at $\nu = 1639\ \mathrm{cm}^{-1}$ and $700\ \mathrm{cm}^{-1}$. The small peak at $\nu = 2900\ \mathrm{cm}^{-1}$ showed the presence of C–H stretching for alkanes. These functional groups will have a bending peak at $\nu = 1379\ \mathrm{cm}^{-1}$ and $1018\ \mathrm{cm}^{-1}$ (CH_2 bend). The C=O carbonyl peaks for polyamide was present at $1697\ \mathrm{cm}^{-1}$ for stretching, and $700\ \mathrm{cm}^{-1}$ for bending, that also overlapped with N–H bending (fingerprint).

3.2. Microplastics in zooplankton

Microplastics were detected in all zooplankton groups examined (cyclopoids, calanoids, polychaetes, shrimps and zoea, chaetognaths and fish larvae). These six major groups accounted for over 62% of total zooplankton abundance with a density that ranged from 328 (ST 5) – 1190 (ST 1; Pulau Karah) ind. m^{-3}. Microplastics that were ingested by zooplankton groups were diverse in size, with fragments being the most common type of microplastics beside fibers (Table 1). Zooplankton at ST 5 and ST 3 (Pulau Redang) were found to have ingested exclusively microplastic fibers while both fibers and fragments appeared to have been ingested by the zooplankton sampled at the other areas.

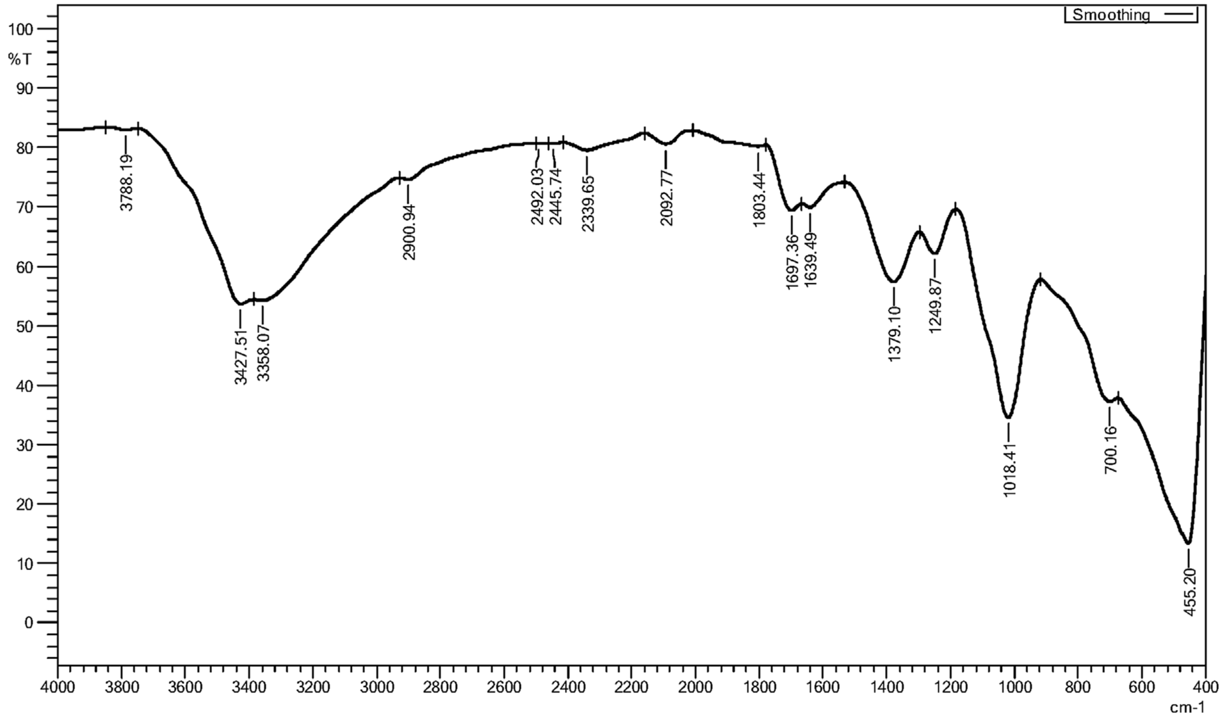

Fig. 3. FTIR spectrum for polyamide type of polymer.

Table 1
Characteristic of plastic ingested by zooplankton collected from all stations.

Stations	Particle ingested	Fibers (%)	Fragments (%)	Fiber size (μm)	Fragment size (μm)	Total zoo. density (ind. m^{-3})	Microplastics ingested (particle m^{-3})
1 ($n = 984$)	8	25 ± 40	75 ± 40	313 ± 127	73.5 ± 49	1190	9.54
2 ($n = 796$)	6	33 ± 41	67 ± 41	503 ± 270	49.5 ± 26	479	3.62
3 ($n = 492$)	3	100 ± 45	–	567 ± 368	–	375	2.29
4 ($n = 559$)	2	50 ± 19	50 ± 19	115 ± 63	60 ± 24	565	2.02
5 ($n = 289$)	5	100 ± 39	–	1135 ± 961	–	328	5.68
All sites ($n = 3120$)	24	44 ± 38	56 ± 38	534 ± 372	61 ± 12	438	4.20

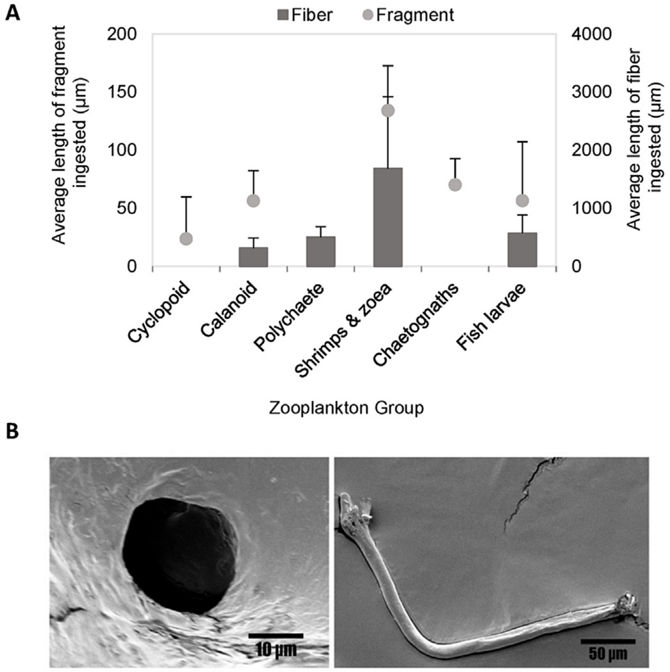

Fig. 4. A). Size of microplastics ingested by different zooplankton groups and B). Examples of microplastic under the scanning electron microscope (SEM).

The average length of the ingested fibers and fragments were 534 ± 372 µm and 61 ± 12 µm respectively (Fig. 4). The average size of microplastic particles for both fibers and fragments was greater in shrimps and zoea (1681 µm and 127 µm respectively) than the other groups of zooplankton, which corresponded to its body size which was up to 1 cm, followed by fish larvae (875 µm and 56.4 µm, respectively), polychaetes (625 µm, fiber), calanoids (313 µm and 56.3 µm, respectively), chaetognaths (54.0 µm, fragment) and cyclopoids (23.5 µm, fragment). Although it was observed that microplastic ingestion corresponded to zooplankton body size, no significant relationship was observed in the current study ($p > 0.05$).

The total number of microplastics ingestion incidence per individual of zooplankton was 0.003, 0.007, 0.01, 0.13, 0.14, which makes up for an average of 1%, 9%, 15%, 15%, 23% and 38% in chaetognath, cyclopoid, polychaete, shrimps and zoea, calanoid and fish larvae, respectively (Fig. 5a). Contrastingly, by combining the microplastic ingestion per individual and zooplankton abundances, the average microplastic abundance in zooplankton community was 2.04, 1.71, 0.63, 0.60, 0.24 and 0.03 particles m^{-3} for cyclopoids, calanoids, fish larvae, polychaetes, shrimp and zoea and chaetognaths, respectively (Fig. 5b). The amount of microplastics ingested can clearly be seen through this order of total number of particles consumed - copepods (cyclopoid and calanoid) (58%) > fish larvae (20%) > polychaetes (12%) > shrimp and zoea (9%) > chaetognaths (1%). The estimated microplastic abundance per cubic meter was shown to be highest at ST1 (Pulau Karah; 9 particles m^{-3}) and lowest at ST4 (Pulau Redang; 2 particles m^{-3}) (Table 1). In this study, no significant differences on ingestion and abundance were observed between stations due to the small number of particles ingested in the analysis ($p > 0.05$).

No significant relation was observed between the number of microplastic abundance in zooplankton community and microplastic concentration in seawater, but the ingestion of fiber in zooplankton correlated significantly with the total concentration of microplastics in seawater ($r^2 = 0.699$, $p < 0.05$).

4. Discussion

4.1. Microplastics in seawater

This study confirms the presence of plastic micro-debris throughout the subsurface waters of the study area as microplastics were present in all samples. Interestingly, when we compare the results of the current study with other studies of its kind, it can be seen that the abundance of microplastics were higher than those reported in Asia and other regions (Desforges et al., 2014; Kosore et al., 2018; Lattin et al., 2004; Sun et al., 2018; Zhao et al., 2014). However, since there is an absence of a standard protocol for microplastic analysis, comparing the samples collected in this study with other reports was difficult. To further justify the previous statement, many studies have used different net types and mesh sizes with different criteria for sorting and determining the cut-off size (Song et al., 2015) but, when cross-referenced to other studies that use similar mesh size, the mean concentrations reported here were comparable to those reported at the Yantai-Qinzhou coastline (0.68–6.44 particles/L; Qu et al., 2018), and in Terengganu and Pahang, Malaysia (0.13–0.69 particles/L; Khalik et al., 2018).

Fibers, which make up a majority of the microplastic particles found in the current study was detected at station near the shore compared to other areas. The results here are consistent with studies reporting that human activities are the greatest influence on microplastic distribution in the marine environment (Browne et al., 2011; Collignon et al., 2012; Sun et al., 2018). The increased concentrations of plastics near shore was in part, explained by the large number of fiber content, which are mostly identified as polypropylene, polyester, polyethylene, polyamide (nylon), acrylic, and polyvinyl alcohol (Browne et al., 2011; Claessens et al., 2013; Sun et al., 2018). These polymers are often used in textiles. For instance, polyamide is widely used to make ropes, nets, and fishing lines. This type of polymer was expected due to fishing, recreational boating, and/or wastewater effluent. Contrastingly, a recent study in Terengganu waters recorded fragment-type microplastics as the dominant shape, accounting for 76.2% of the total microplastics, indicating that a variation on the marine debris pollution could vary spatially and temporally. Nonetheless, this finding provides an important baseline to monitor subsequent changes on the occurrence of microplastics in seawater.

4.2. Microplastics in zooplankton

The present study documented that zooplankton do indeed, ingest microplastics in the areas off the Terengganu coast and demonstrated low ingestion incidence in zooplankton groups from all sites. These

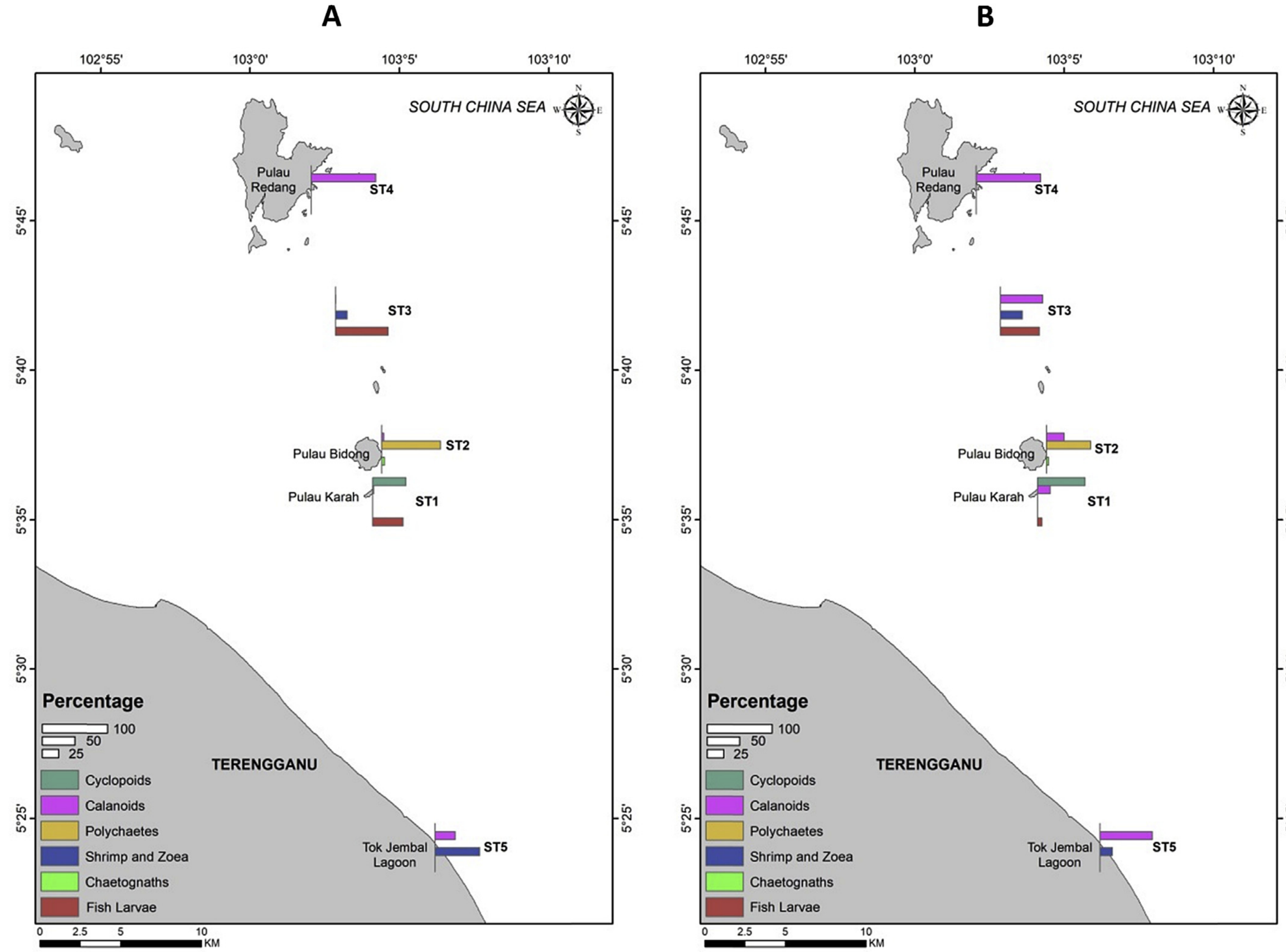

Fig. 5. A) The ingestion incidence (in percentage) between microplastics and zooplankton groups, B) number of microplastic abundance in zooplankton community (in pecentage) as a whole in the study area.

results are in accordance with previous studies reported in the Northeast Pacific Ocean (0.03–0.06 particles/zooplankton; Desforges et al., 2015), Portuguese coastal waters (0.04–0.14; Frias et al., 2014) and Kenya's marine environment (0.16–0.46; Kosore et al., 2018) but slightly lower than that in Yellow Sea (0.07–1.17; Sun et al., 2018).

The microplastics found in the different groups of zooplankton demonstrated inconsistent microplastic ingestion and abundance, indicating that the distribution of microplastics in zooplankton community are dependent on zooplankton abundance and number of microplastic per individual of each taxon at different stations. Nevertheless, the presence of microplastic in each zooplankton found in this study have been previously reported elsewhere (Carpenter et al., 1972; Desforges et al., 2015; Kosore et al., 2018; Sun et al., 2017, 2018). However, the same cannot be said with the polychaete samples examined as there are no reports on microplastic ingestion in natural seawater, but laboratory experiments have confirmed the ingestion of 3 μm and 10 μm neutral-density polymer microsphere (Bolton and Havenhand, 1998). By comparing the size of microplastics ingested in zooplankton from other studies, the present results showed a similar size range reported in Northern South China Sea; 125–167 μm (Sun et al., 2017), Northeast Pacific; 168–299 μm (fragment) and 461–1778 μm (fiber) (Desforges et al., 2015). Although it was observed that microplastic ingestion corresponded to zooplankton body size, no significant relationship was observed in the current study. This suggests that the similarity among groups may occur due to a trophic transfer on microplastics, either directly through mistaking microplastics as prey items or indirectly through ingesting prey items that have already consumed microplastics (Cole et al., 2013; Di Mauro et al., 2017; Sun et al., 2017).

On the other hand, microplastic analysis in seawater produced contrasting results as fragments were more commonly detected compared to the fibers found in zooplankton. This difference in results can be explained by the relation between duration of time microplastics accumulated in the area with zooplankton distribution. It has been reported that environmental conditions such as wind direction, current, precipitation and atmospheric depositions play a vital role in the distribution of microplastics and their final sinking point (Dris et al., 2016; Kukulka et al., 2012; Reisser et al., 2015). In the case of zooplankton, some groups that display diel vertical migration have been shown to influence their distribution patterns (Williamson et al., 2011) and thus, pose the possibility of affecting microplastic ingestion by them. However, depth profiles for microplastics are needed to quantitatively confirm this hypothesis.

In feeding experiments with several zooplankton taxa, several studies concluded that the risk of plastic ingestion might be attributable to food abundance as well as feeding habits, anatomy of feeding/digestive organs of the consumer and food size similarity (Hämer et al., 2014; Kaposi et al., 2014; Setälä et al., 2014). Kiorboe (2011) reported that mechano- and chemoreceptors were observed in zooplanktons as sensory organs that are used to recognize and differentiate food items. Several copepods species preferred ingesting aged microplastics compared to pristine plastic, suggesting that microplastics that developed biofilms within the marine environment may generate a chemosensory response (Lobelle and Cunliffe, 2011; Vroom et al., 2017). Some zooplankton even have the ability to ingest or reject prey upon capture, depending on surface characteristics and particle charges (Hart, 1991). Nonetheless, egestion rate was also likely to affect the finding. It is also possible that spherical or granular shaped particles are more easily removed from the digestive tract (Farrell and Nelson, 2013), while the egestion of synthetic fibers is more equivocal and prolonged in crustaceans due to the complexity of their digestive tract. Powell and Berry (1990) reported the ability of estuarine copepod *Eurytemora affinis* to egest latex beads (15 μm) between 1 and 3 h after ingestion while some *Calanus helgolandicus* individuals retain polystyrene bead for up to 7 days (Cole et al., 2013). Nevertheless, only a small number of studies and laboratory trials have been done on fibrous microplastics and therefore, it is unclear whether the residence time of these particles is comparable to that of spheres (Watts et al., 2014).

On the other hand, Christaki et al. (1998) found that the size of microplastic fibers played a key role in clearance rate in ciliate *Strombidium* for plastic microsphere (0.75 μm) were indistinguishable from those fluorescently labeled algae cells. Some zooplankton like calanoids, shrimps and fish larvae can feed on prey items which can reach lengths of up to 1.54 mm (Baier and Purcell, 1997), equivalent to the fibers encountered in this study. In reality, fibers can naturally be folded or twisted or bundled into an aggregate. Thus, reducing their overall size and potentially increasing their bioavailability (Desforges et al., 2015).

To summarize, the results from this study has successfully showed that zooplankton sampled from different areas off the Terengganu coast in Southern South China Sea are able to ingest microplastics. Although it was a small-scale study, it has been able to provide useful information on microplastic pollution and thus, should be immediately addressed and controlled. The present study also happens to be the maiden work done in Malaysian surface water to highlight microplastic ingestion in zooplankton. Consequently, this study further justifies the importance of more studies on plankton survey, both spatially and temporally to be done as the variation in zooplankton abundance and distribution may vary based on locality and season. Besides that, knowledge on the mechanism of microplastic transfer across the food web and implications on their health still remains unclear. Setälä et al. (2014) reported that microplastics can potentially be transferred via planktonic organisms from one trophic level to a higher trophic level. The transfer of microplastics between trophic levels has already been demonstrated among adult marine invertebrates. The investigation of trophic transfer of microplastics from fishes to marine mammals showed that 48% of 31 seal scats contained ethylene, propylene and polypropylene of plastic polymer (Nelms et al., 2018), suggesting that translocation of additive chemicals in microplastics may occur along the marine food web. Cole et al. (2016) demonstrated that microplastics can also be indirectly ingested via consumption of fecal pellets, thereby highlighting fecal pellets as a novel vector for microplastics. As zooplankton are highly vulnerable to predation, this may provide a direct or indirect route for microplastics to potentially be transferred through trophic levels and thus, creating adverse health consequences in higher trophic organisms.

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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.2019.110616.

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