Microplastic in cultured oysters from different coastal areas of China

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HIGHLIGHTS
• Microplastic uptake was identified in cultured oysters from 17 cites of China.
• Eighty-four percent of sampled oysters had inhaled microplastics.
• The average microplastics abundance was 0.62 items/g (ww) or 2.93 items/individual.
• The most common polymeric types of microplastics in oysters were CP, PE and PET.

GRAPHICAL ABSTRACT

ABSTRACT
Microplastics are an emerging concern in the marine environment due to their small size; they can be ingested by aquatic organisms, especially filter-feeding organisms, such as oysters. The presence of microplastics in seafood may pose a threat to food safety, and there is an urgent need to evaluate the potential risks of microplastics to human health. This study quantified the microplastics in oysters from 17 sites along the coastline of China. Qualitative attributes, such as shape and size, were also determined under a microscope. Additionally, the polymer types were identified using Fourier-Transform Infrared Micro-Spectroscopy (μ-FT-IR). The results showed that the average abundance of microplastics in oyster was 0.62 items/g (wet weight) or 2.93 items/individual. Additionally, 84% of the sampled oysters had inhaled microplastics, indicating the high prevalence of microplastic pollution in different coastal areas of China. Fibers were the most common shape (60.67%), and the most common size was <1500 μm, accounting for 81.89% of the total microplastics. The μ-FT-IR analysis identified eight different polymers, and the main polymeric types of microplastics were cellophane (CP), polyethylene (PE) and polyethylene terephthalate (PET). Our results suggest the widespread prevalence of microplastics in cultured oysters from different coastal areas of China with similar or lower abundances than other countries. In addition, our results exhibited regional characteristics of high microplastics abundance in southern coastal area of China and low microplastics abundance in northern China. Further investigations are warranted to examine microplastics contamination in other seafood species from different geographical sites in coastal area of China.

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1. Introduction

Over the past century, plastic demand and production have increased exponentially, reaching 335 million tons in 2016 (Plastics Europe, 2018). The large-scale use of plastic products and poor management by consumers have resulted in 10% of plastics ending up in oceans (Thompson et al., 2009). It is estimated that approximately 5.35 trillion plastic particles float on the surface of oceans and seas (Eriksen et al., 2014). Thus, marine plastic pollution has become a global environmental concern. Microplastics, defined as particles < 5 mm (Arthur et al., 2009), have been widely observed in different environmental media including the water column (W. Zhang et al., 2017; Cincinelli et al., 2017) and offshore and deep-sea sediments (Peng et al., 2017; Van Cauwenberge et al., 2013; Bergmann et al., 2017).

Because of their small dimensions, microplastics are easily mistaken for food, and they have been ingested by a wide range of marine organisms with different feeding mechanisms, including zooplankton (e.g., Cole et al., 2013; Desforges et al., 2015; Sun et al., 2016), filter-feeding bivalves (e.g., Van Cauwenberge et al., 2015; Li et al., 2016), deposit-feeding lugworms (e.g., Van Cauwenberge et al., 2015), fishes (e.g., Lusher et al., 2013, 2015; Bellas et al., 2016; Nadał et al. 2016; Güven et al., 2017), and crustaceans (e.g., Devriese et al., 2015; Welden and Cowie, 2016; Setälä et al., 2014). The filter-feeding mode of bivalves makes them one of the main target species of studies on microplastic ingestion. Additionally, bivalves are usually preyed upon by many vertebrates and invertebrates, and they are the main source of seafood for human consumption worldwide (Davidson and Dudas, 2016). Moreover, humans are apt to ingest microplastics when they consume these bivalves, so monitoring the abundance of microplastics in bivalves is very important. So far, much of the evidence from field studies has demonstrated a high abundance of microplastic ingestion in bivalves, particularly in commercially important mussels, clams and oysters (Mathalon and Hill, 2014; Van Cauwenberge et al., 2015; Van Cauwenberge and Janssen, 2014; Vandermeersch et al., 2015; Li et al., 2015, 2016; Santana et al., 2016; Davidson and Dudas, 2016). The abundance of microplastics ingested by oysters from the eastern coast of Thailand varied from 0.37 to 0.57 particles/g (Thushari et al., 2017). De Witte et al. (2014) found that the abundance of microplastics was 3.73 items/g in mussels collected from Belgian department stores, groceries and quaysides. In China, microplastics in 9 bivalves species was 3.73 items/g in mussels collected from Belgian department stores, individual (Li et al., 2015); meanwhile, the microplastics abundance in bivalves, particularly in commercially important mussels, clams and oysters (e.g., Cole et al., 2013; Desforges et al., 2015; Sun et al., 2016), filter-feeding bivalves (e.g., Van Cauwenberge et al., 2015; Li et al., 2016), deposit-feeding lugworms (e.g., Van Cauwenberge et al., 2015), fishes (e.g., Lusher et al., 2013, 2015; Bellas et al., 2016; Nadał et al. 2016; Güven et al., 2017), and crustaceans (e.g., Devriese et al., 2015; Welden and Cowie, 2016; Setälä et al., 2014). The filter-feeding mode of bivalves makes them one of the main target species of studies on microplastic ingestion. Additionally, bivalves are usually preyed upon by many vertebrates and invertebrates, and they are the main source of seafood for human consumption worldwide (Davidson and Dudas, 2016). Moreover, humans are apt to ingest microplastics when they consume these bivalves, so monitoring the abundance of microplastics in bivalves is very important. So far, much of the evidence from field studies has demonstrated a high abundance of microplastic ingestion in bivalves, particularly in commercially important mussels, clams and oysters (Mathalon and Hill, 2014; Van Cauwenberge et al., 2015; Van Cauwenberge and Janssen, 2014; Vandermeersch et al., 2015; Li et al., 2015, 2016; Santana et al., 2016; Davidson and Dudas, 2016). The abundance of microplastics ingested by oysters from the eastern coast of Thailand varied from 0.37 to 0.57 particles/g (Thushari et al., 2017). De Witte et al. (2014) found that the abundance of microplastics was 3.73 items/g in mussels collected from Belgian department stores, groceries and quaysides. In China, microplastics in 9 bivalves species from the Shanghai fish market were ranged from 4.3 to 57.2 particles/individual (Li et al., 2015); meanwhile, the microplastics abundance varied from 1.5 to 7.6 items/individual in mussels collected from the coastline of China (Li et al., 2016). A previous study reported that top European consumers can ingest up to 11,000 microplastics per year through shellfish consumption while minor mollusk consumers had a dietary exposure to 1800 microplastics per year (Van Cauwenberge and Janssen, 2014). By now, it is generally accepted that microplastics contamination caused by transportation or other environmental factors, the collected samples were packed in aluminum foil and placed in a 4 °C refrigerator, then transported to the laboratory and stored at −20 °C until further examination.

2. Materials and methods

2.1. Oyster sampling

Oysters (Crassostrea gigas, Crassostrea angulate, Crassostrea hongkongensis and Crassostrea sikamea) were purchased from local culture farms from 17 sites along the coastline of China from March to May 2016 (Fig. 1). The sampling locations of oysters included Dandong (S1), Dalian (S2), Jinzhou (S3), Qinhuangdao (S4), Tianjin (S5), Changdao (S6), Qingdao (S7), Lianyungang (S8), Nantong (S9), Ningbo (S10), Wenzhou (S11), Putian (S12), Xiamen (S13), Shantou (S14), Shenzhen (S15), Zhanjiang (S16) and Beihai (S17). At each site, at least 30 individuals were sampled and delivered to our lab with ice. In order to avoid microplastics contamination caused by transportation or other environmental factors, the collected samples were packed in aluminum foil and placed in a 4 °C refrigerator, then transported to the laboratory and stored at −20 °C until further examination.

Fig. 1. Sample sites of the cultured oysters along the coastline of China.
2.2. Digestion of biological samples

Eighteen oyster animals were taken out from the freezer and thawed for 1 h for each site. The oyster shells were rinsed thoroughly with water, and the shell length and shell height of each individual were measured using a vernier caliper (the data is shown in Table 1.). The oysters were dissected and the wet weight of the soft tissues was determined by precision electronic balances (Table 1). The oyster soft body digestion was carried out according to the method of Munno et al. (2018), with some minor modifications. The microplastic separation method is briefly described as follows: each individual was placed into a labelled 500 mL glass beaker. Three glass beakers comprised one replicate, and six replicates were prepared for each site. Approximately 180 mL of 10% (m/v) KOH and 20 mL of 30% H2O2 were added to each glass beaker to digest the soft tissues. The beakers were covered with aluminum foil and placed in an oven at 60 °C for 48 h. At the same time, the mixture was agitated once every 8 h. When there was no visible organic residue and the solution was clear and yellow, the digestion was considered completed. The mixed solutions were then vacuum-filtered over 1.0 μm glass microfiber filters (Whatman GF/B). Finally,

| Sites   | Length (cm) | Height (cm) | Weight (g) |
|---------|-------------|-------------|------------|
| North China |             |             |            |
| S1      | 6.12 ± 0.97 | 3.92 ± 0.43 | 5.61 ± 2.48 |
| S2      | 9.88 ± 0.68 | 5.20 ± 0.54 | 13.53 ± 3.03 |
| S3      | 11.26 ± 1.31| 6.19 ± 0.62 | 16.06 ± 3.36 |
| S4      | 8.20 ± 0.90 | 5.29 ± 0.59 | 12.88 ± 2.87 |
| S5      | 9.43 ± 2.59 | 3.96 ± 0.78 | 11.52 ± 6.50 |
| S6      | 6.94 ± 1.10 | 2.91 ± 0.84 | 7.94 ± 2.39  |
| S7      | 5.80 ± 0.99 | 3.69 ± 0.75 | 5.81 ± 2.43  |
| S8      | 8.61 ± 0.94 | 4.56 ± 0.80 | 12.19 ± 4.13 |
| South China |            |             |            |
| S9      | 4.45 ± 1.33 | 2.91 ± 1.32 | 3.13 ± 2.34  |
| S10     | /           | /           | 7.84 ± 2.80  |
| S11     | 4.50 ± 0.91 | 3.23 ± 0.75 | 3.13 ± 1.29  |
| S12     | 5.91 ± 0.55 | 3.69 ± 0.54 | 5.69 ± 1.30  |
| S13     | 4.44 ± 0.67 | 2.86 ± 0.66 | 2.70 ± 0.84  |
| S14     | 8.24 ± 0.71 | 4.84 ± 0.37 | 8.72 ± 1.54  |
| S15     | 6.74 ± 0.87 | 4.82 ± 0.56 | 10.15 ± 2.77 |
| S16     | 10.02 ± 1.07| 6.02 ± 0.79 | 14.47 ± 3.02 |
| S17     | 4.67 ± 0.90 | 3.22 ± 0.78 | 3.46 ± 1.62  |

Note: / indicates that the value is missing.

Table 1 Shell dimensions and body weights of the cultured oysters from different coastal areas of China.

![Fig. 2. Abundance of microplastics in cultured oysters at each site of China on the map. The average value of microplastic per gram (w.w.) is indicated by a yellow bar at each site, and the blue bar represents the average of microplastic per individual at each site.]
Fig. 3. Box-whisker plot for microplastic abundance in oysters along the coastline of China. The box plots represent the 1st and 3rd quartiles separated by the median. Outliers are plotted individually (blue dot). The abundances of microplastics are given as the number of plastic particles per gram of oyster tissue (A) and per individual (B). Six replicates were set for oysters at each site, and the means in two random groups that do not have the same letter are significantly different at $P < 0.05$. 
the filters were dried at room temperature in individual glass petri dishes which were secured with tape and stored until analysis.

2.3. Microscopic inspection

All the filters were observed carefully by a z-shaped pattern from left to right under a stereomicroscope (Olympus, SZX10, Japan) to analyze the presence of microplastics. A fiber optic halogen lamp (Olympus LG-P52) was used for cold light illumination. Microplastic particles were visually identified according to the colour, lack of biological features and structure of the particles in accordance with Hidalgo-Ruz's et al. (2012) protocol: (1) the colour of the particles is homogeneously distributed; (2) no tissue or cell structures are visible; and (3) if the particle is a fiber, it should be equally thick, not taper towards the ends and have a three-dimensional bending. If necessary, tweezers can be used to check whether a particle is a microplastic. If it breaks, it is not a microplastic. Then, the abundance and shape of the microplastics was recorded. All of the suspected microplastics on filters were classified into four morphotypes, including fibers, fragments, plastic films and particles. In addition, based on the largest dimension (length), every particle was assigned to one of seven distinct size classes: 1–500, 501–1000, 1001–1500, 1501–2000, 2001–3000, 3001–4000 and 4001–5000 μm. Each shape of microplastic was enumerated and photographed by the microscope equipped with a camera (Cnoptec TP510, Chongqing, China).

2.4. Microplastic identification

A total number of 301 common and undeterminable particles were randomly picked with tweezers from the filters and verified with a micro-Fourier Transformed Infrared Spectroscope (μ-FT-IR) in transmittance mode. The μ-FT-IR analysis was measured using a NicoletTM iN10 infrared microscope (Thermo Fisher Scientific, USA) equipped with an ultra-fast motorized stage and a single MCT detector, which was cooled in liquid nitrogen. Each spectrum was recorded in the spectral range 650–4000 cm⁻¹ by co-adding 128 scans at a resolution of 8 cm⁻¹. The aperture size ranged from 50 × 50 μm to 150 × 150 μm depending on the size of the microplastics. The obtained spectra were compared with the OMNIC polymer spectra library, and the type of microplastics was determined when the match rate was higher than 70% (Directive, 2013).

2.5. Contamination prevention

Strict control measures were implemented in the laboratory analyses to mitigate airborne and lab contamination. All of the equipments were rinsed three times with 200 mL Milli Q water and then dried before the experiments. Once dried, they were immediately kept under aluminum foil to prevent contamination with airborne microplastics. During the experiments, cotton laboratory coats and polymer-free gloves were always worn. The movement of people was minimized in the laboratory, and the lab windows were closed throughout the experiments. Additionally, three procedural blanks without oyster tissue but others same as the digestion process were set up to correct for the potential procedural contamination.

2.6. Statistical analysis

All results regarding microplastic abundances are given as the number of plastic particles per gram of oyster tissue or per individual. All statistical analyses were performed using SPSS 16.0 software (SPSS Inc., Chicago, IL, USA). The non-parametric Kruskal-Wallis H test was used to analyze multiple comparisons. If the test indicated significant differences, the pair-wise Mann–Whitney U test was used for comparisons with a significance level of 0.05. All values are reported as the mean ± standard deviation (mean ± SD).

3. Results

3.1. Abundance of microplastics in oysters

The three samples representing procedural blanks showed a value of 1.2 ± 0.7 items/sample, and the contamination was removed when the microplastic abundance was counted. Additionally, the microplastic abundance was calculated by removing the identified non-plastic particles. Our results indicate that microplastics were widely detected in cultured oysters from the coastline of China, with a total number of 1218 items. The average abundance of microplastics was 0.62 items/g (ww) or 2.93 items/individual in oysters.

The quantitative results of microplastic in oysters for each sampling location are presented in Figs. 2 and 3. The mean values of microplastic abundances in the sampling sites are shown in Table 2. The abundance of microplastics in oysters from the S13 site was 2.35 items/g, which was the highest level of microplastic contamination assessed by weight. In addition, the microplastics abundance of S13, S12 and S15 was significantly higher than that of S3, S5, S14 and S16 when expressed as items/g of wet weight (P < 0.05). However, the oysters collected from the S15 site showed the highest contamination level (9.08 items/individual) assessed by individual. Furthermore, according to items/individual unit, the microplastics abundances of S15 and S13 were significantly higher than those of other sampling sites (P < 0.05). Additionally, the level of microplastics in oysters collected from the southern area (S9, S10, S11, S12, S13, S14, S15, S16 and S17) of China was 0.887 items/g (ww) or 3.40 items/individual, whereas the level was 0.328 items/g (ww) or 2.41 items/individual in oysters collected from the northern area (S1, S2, S3, S4, S5, S6, S7 and S8) of China.

Microplastics were detected in 84% of the oysters sampled along the coastline of China. As shown in Fig. 4, the oysters collected from the S3 site had the lowest uptake rate, with only 63% of the total individuals containing microplastics. However, the oysters collected from the S8 site had an uptake rate of 100%, showing the highest contamination level. The ascending order of the microplastic uptake rate of oysters was S3 < S6 < S4 = S16 < S15 < S1 = S2 = S10 < S7 < S9 < S13 < S5 = S14 < S11 < S12 < S17 < S8.

3.2. Shape and sizes of microplastics in oysters

Four different shapes of microplastics were present in the oyster samples: fibers, fragments, films and pellets (Fig. 5). The major shape of microplastics in oysters was categorized as fibers (60.67%), followed by fragments (19.95%) and films (10.26%), whereas pellet

Table 2

| Sites       | Microplastic abundances (items/g) | Microplastic abundances (items/individual) |
|-------------|----------------------------------|------------------------------------------|
| North China |                                  |                                          |
| S1          | 0.26 ± 0.29                      | 1.52 ± 1.06                              |
| S2          | 0.83 ± 1.29                      | 4.12 ± 6.05                              |
| S3          | 0.14 ± 0.16                      | 1.95 ± 1.84                              |
| S4          | 0.33 ± 0.21                      | 4.00 ± 2.25                              |
| S5          | 0.19 ± 0.22                      | 1.46 ± 1.41                              |
| S6          | 0.21 ± 0.20                      | 1.67 ± 1.24                              |
| S7          | 0.42 ± 0.40                      | 1.96 ± 1.43                              |
| S8          | 0.25 ± 0.24                      | 2.63 ± 2.28                              |
| South China |                                  |                                          |
| S9          | 0.77 ± 0.91                      | 1.67 ± 1.17                              |
| S10         | 0.19 ± 0.19                      | 1.50 ± 1.25                              |
| S11         | 1.32 ± 1.22                      | 3.12 ± 2.33                              |
| S12         | 1.42 ± 0.68                      | 5.19 ± 2.59                              |
| S13         | 2.35 ± 1.39                      | 5.63 ± 2.45                              |
| S14         | 0.12 ± 0.11                      | 1.05 ± 1.03                              |
| S15         | 1.00 ± 0.72                      | 9.08 ± 5.70                              |
| S16         | 0.11 ± 0.10                      | 1.50 ± 1.22                              |
| S17         | 0.70 ± 1.05                      | 1.84 ± 1.75                              |
microplastics (9.11%) were the least abundant in oysters (Fig. 6A). As illustrated in Fig. 6B, the mean size of the microplastics inhaled by oysters was $902.82 \pm 782.99 \mu m$, ranging from 20.34 to 4807.22 \mu m. The microplastics $< 500 \mu m$ in size were the most common and accounted for 38.57% of the observed microplastics. Additionally, the category percentages for 500–1000 \mu m and 1000–1500 \mu m were 28.09% and 15.23%, respectively, whereas large microparticles (approximately 1500–5000 \mu m) were rarely observed (18.10%).

3.3. Composition of microplastics in oysters

Three hundred and one particles were selected from 1218 visually identified particles and further validated with \mu-FT-IR. Two hundred and eighty-three particles were identified as microplastics among the 301 particles analyzed, so our visual sorting was effective because $\approx 90\%$ of the particles were proven to be microplastics. Among the 283 validated particles found in the sampled oysters, eight different

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**Fig. 4.** Microplastic uptake rate (%) of the cultured oysters along the coastline of China.

**Fig. 5.** Optical microscope images of selected microplastics isolated from the cultured oysters along the coastline of China. A: particle, B: fragment, C: film, D-F: fiber.
Polymeric types of plastic were determined, including cellophane (CP), polyethylene (PE), polyethylene terephthalate (PET), polypropylene (PP), polyamide (PA), polystyrene (PS), polycarbonate (PC) and polyvinyl chloride (PVC). The μ-FT-IR spectrum of each type of microplastic is shown in Fig. 7. The quantity of each type of microplastic polymer observed in oysters is presented in Table 3. The major polymeric types of the microplastics detected in the samples were CP and PE with respective proportions of 41.34% and 22.97% of the total identified particles. PET, PP, PA, PS, PC and PVC accounted for 15.19%, 9.89%, 4.95%, 2.47%, 1.77% and 1.41% of the particles, respectively.

4. Discussion

4.1. Concentration of microplastics in oysters

In this study, we investigated microplastic in oysters collected from a large geographical area along the coastline of mainland China for the first time. Our results revealed that 84% of the sampled oysters had uptake microplastics, suggesting that the coastal seawater of China is contaminated by microplastics. It was not surprising that cultured oysters inhaled microplastics because they are mainly cultured on ropes or structures built on the seabed in coastal area (Li et al., 2011; Van Cauwenbergh and Janssen, 2014; Yu et al., 2016). As a result, these cultured oysters can be exposed to microplastics in seawater. The average abundance of microplastics was 0.62 items/g (wet weight) in the present study. Compared with the abundance of microplastics in bivalves reported in other areas (Table 4), this value was in accordance with the observation of microplastics in oysters from Thailand, French and Belgium (Thushari et al., 2017; Van Cauwenbergh and Janssen, 2014; De Witte et al., 2014) despite different sample preparation protocols and analysis methods. In addition, the quantities of microplastics found in oysters was lower than those documented in mussels from the Netherlands, China and England (Leslie et al., 2013; Li et al., 2016; Catarino et al., 2017). When expressed as microplastics per individual, the average abundance of the microplastics was 2.93 items/individual, which was comparable with that of oysters from France (Phuong et al., 2017) but significantly lower than that of mussels from Canada (Mathalon and Hill, 2014). Different microplastic analysis methods, different sampling sites and the physiological differences between oysters and mussels may be related to the differences between these studies and our study. Moreover, the microplastics < 20 μm could not be effectively detected and enumerated by the method used in this study, so the abundance and size distribution of microplastics in the cultured oysters might be underestimated.

Our results also demonstrated that the contamination levels of microplastics in oysters were different between the southern and northern areas of China, and the abundance of microplastics in oysters collected from the southern area was significantly higher than the oysters collected from the northern areas when expressed as items/g of wet weight ($P < 0.05$). It has been shown that the levels of microplastics in oysters and other bivalves were strongly related to the microplastic abundance in the water column in which they lived (Li et al., 2018; Qu et al., 2018; Su et al., 2018). Although this study did not investigate the abundance of microplastics in the water column and sediment

![Figure 6](image-url)
from different coastal areas of China, the abundance of microplastics in oysters may correspond with the level of microplastic pollution in the environment. A previous study showed a high abundance of microplastics in the water of Minjiang, Jiaojiang and Oujiang, with values of 1245.8 ± 531.5, 955.6 ± 848.7 and 680.0 ± 284.6 items/m$^3$, respectively (Zhao et al., 2015). These sampling sites are near the S11, S12 and S13 sites in our study. In addition, the abundance of microplastics in the sediment of the coastal area of Guangdong, where the S15 site is located, was 6675 items/m$^2$ (Fok et al., 2017). However, the abundance of microplastics in the surface waters of the Bohai Sea was 0.33 ± 0.34 items/m$^3$ (Zhang et al., 2017), which was much lower than the previous three estuarine areas (Minjiang, Jiaojiang and Oujiang). The S3, S4 and S5 sites are located in the Bohai Sea, but they are a little far from the above sampling sites in the Bohai Sea. Thus, the abundance of microplastics in oyster samples might reflect the level of plastic contamination of their living environment, and oysters could be used as bioindicators of plastic pollution in coastal and marine environments. However, the presence of microplastics in oysters only means that oysters will inadvertently ingest microplastics with food during the filter-feeding activities, which does not prove that oysters can actively ingest microplastics. Additionally, the data of microplastics pollution level from oyster living environments including water and sediment are still needed to further verify that oysters are a good indicator organism.

According to the quantitative results, the abundance of microplastics in oysters from different sites varied greatly when expressed as items/g of wet weight soft tissue compared with the results expressed as items/individual. This was mainly manifested in an upward trend in the southern coastal area of China, whereas in the northern coastal area of China there is a downward trend. According to the physiological indicators of the samples (Table 1), the weight of the oysters in the southern coastal area of China was significantly lower than the northern coastal area of China ($t$-test, $P < 0.05$). These results indicate that the number of microplastics found in oyster's tissues could be inversely proportional to the weight of the organism.

4.2. Qualitative attributes of microplastics in oysters

Qualitative features such as shape and type of microplastics can provide information about the potential source of their origin. Generally, fibers were the most common shape of microplastics in oysters, which was consistent with the oysters collected from the Pearl River Estuary, China (Li et al., 2018). This was also similar to the observation of

| Type of polymers             | Number | %    | Density g/cm$^3$ | Library                        |
|------------------------------|--------|------|------------------|--------------------------------|
| Cellophane                   | 117    | 41.34| 1.50             | Hummel Polymer Sample Library  |
| Polyethylene                 | 65     | 22.97| 0.89–0.91        | Hummel Polymer Sample Library  |
| Polyethylene terephthalate   | 43     | 15.19| 1.29–1.40        | Cross Sections Wizard          |
| Polypropylene                | 28     | 9.89 | 0.89–0.91        | Polymer Laminate Films         |
| Polyamide                    | 14     | 4.95 | 1.07–1.08        | Hummel Polymer Sample Library  |
| Polystyrene                  | 7      | 2.47 | 1.04–1.08        | Hummel Polymer Sample Library  |
| Polycarbonate                | 5      | 1.77 | 1.20             | Hummel Polymer Sample Library  |
| Polyvinyl chloride           | 4      | 1.41 | 1.3–1.58         | Hummel Polymer Sample Library  |
| Total                        | 283    | 100  |                  | /                              |

Note: The plastic density is referred to Nuelle et al. (2014) and Peng et al. (2017).
microplastic contamination in other species, e.g., *Mytilus edulis*, *Venerupis philippinarum* and *Crangon crangon* (Li et al., 2016; Davidson and Dudas, 2016; Devriese et al., 2015). In addition, this result was also consistent with the observation that fibers were the most abundant shape of microplastic in the sediments of the Yangtze Estuary (Peng et al., 2017), the coast of the South Sea, China (Qiu et al., 2015), the surface water of the Yangtze Estuary (Zhao et al., 2014), and three urban estuaries in China (Zhao et al., 2015). These fibers could have originated mainly from laundry wastewater: a single clothing garment could release >1900 fibers per wash (Browne et al., 2011). In addition, atmospheric compartment was a potential source of microplastics that transported by wind to the aquatic environment (Dris et al., 2016).

Chemical analysis was performed on microplastics found in oysters from 17 sites, with a total of 301 out of the 1218 microplastics (25%) being analyzed. In our study, cellulose was highly predominant among the identified microplastics in all samples. Although cellulose is not a classical oil based polymer, many studies have found that this fiber is high in content and is not easily degraded. Thus, many articles have regarded it as a microplastic, such as Li et al. (2016) found that cellulose microfibers were the most abundant polymer type of mussels from Chinese coastal environment. Bråte et al. (2018) also found that cellulose-based particles were the most dominant in Norwegian mussels. In addition, 49% of the plastic polymers found in coastal fish in China were identified as cellulose (Jabeen et al., 2017). There are three possible sources of cellulose which may act in combination: fibers from atmospheric fall-out, fibers released with effluent from WWTPs or fibers from terrestrial application of sludge (Bråte et al., 2018). Additionally, PE and PET were also major polymeric types of microplastics. This result is consistent with the microplastics isolated from three sessile invertebrates (*Saccostrea forskalii*, *Balanus Amphitrite*, and *Littoraria sp.*)) in the eastern coast of Thailand (Thushari et al., 2017) and two bivalves (*Mytilus edulis*, *Crassostrea gigas*) from the French Atlantic coast (Phuong et al., 2017). PE and PET are commonly used in packaging applications, cosmetic and insulation materials.

Finally, regarding the size, the predominant was <500 μm in range. The microplastics found in oysters were on average bigger than those found in mussels (Van Cauwenbergh et al., 2014; Phuong et al., 2017). Van Cauwenbergh and Janssen (2014) found that the

| Analyzed organism | Microplastic concentrations | Unit | Country and location | References |
|-------------------|-----------------------------|------|----------------------|------------|
| Oyster (*Crassostrea gigas*) | 29 | Particles/g | Oosterschelde, Neltje Jan, Dutch coast | Leslie et al., 2013 |
| Oyster (*Crassostrea gigas*) | 10 | Particles/g | Rhine estuary, Dutch coast | Leslie et al., 2013 |
| Mussel (*Mytilus edulis*) | 10.5 | Particles/g | Oosterschelde, Neltje Jan, Dutch coast | Leslie et al., 2013 |
| Mussel (*Mytilus edulis*) | 1.9 | Particles/g | Ter Heide, North sea coast, Dutch coast | Leslie et al., 2013 |
| Mussel (*Mytilus edulis*) | 0.36 | Particles/g | North sea, Germany | Van Cauwenbergh and Janssen, 2014 |
| Mussel (*Mytilus sp.* (framed mussel)) | 0.47 | Particles/g | Brittany, France | Van Cauwenbergh and Janssen, 2014 |
| Mussel (*Mytilus sp.*) | 126 | Per individual | McCormack’s Beach, Canada | Mathalon and Hill, 2014 |
| Mussel (*Mytilus sp.*) | 106 | Per individual | Rainbow Haven Beach, Canada | Mathalon and Hill, 2014 |
| Mussel (*Mytilus sp.* (framed mussel)) | 178 | Per individual | Halifax Harbor, Nova Scotia, Canada | Mathalon and Hill, 2014 |
| Mussel (*M. galloprovincialis* and *M. edulis/galloprovincialis*) | 3.73 | Fibers/10 g | Belgian department stores, Belgian groyen and quaysides | De Witte et al., 2014 |
| Mussel (*Mytilus edulis*) | 0.13 | Particles/g | Europe | Vandermeersch et al., 2015 |
| Mussel (*Mytilus edulis*) | 0.2 | Particles/g | North Sea | Van Cauwenbergh et al., 2015 |
| Mussel (*M. galloprovincialis*) | 0.14 | Particles/g | Europe | Vandermeersch et al., 2015 |
| Nine bivalves | 2.1–10.5 | Particles/g | China | Li et al., 2015 |
| Clams (*Venerupis philippinarum*) | 1.3 | Particles/g | Baynes Sound, British Columbia | Davidson and Dudas, 2016 |
| Mussel (*Mytilus edulis*) | 2.2 | Particles/g | China | Li et al., 2016 |
| Mussel (*Mytilus edulis*) | 4 | Particles/g | England | Li et al., 2016 |
| Mussel (*Mytilus edulis*) | 2.5 | Particles/g | England | Catarino et al., 2017 |
| Mussel (*Mytilus edulis*) | 12.6 | Particles/g | England | Catarino et al., 2017 |
| Oyster (*Saccostrea forskalii*) | 0.46 | Particles/g | Chonburi Province, Thailand | Thushari et al., 2017 |
| Oyster (*Crassostrea gigas*) | 0.18 | Particles/g | Atlantic coasts, France | Phuong et al., 2017 |
| Oyster (*Crassostrea gigas*) | 2.10 | Particles/g | Atlantic coasts, France | Phuong et al., 2017 |
| Mussel (*Mytilus edulis*) | 0.23 | Particles/g | Atlantic coasts, France | Phuong et al., 2017 |
| Mussel (*Mytilus edulis*) | 0.60 | Particles/g | Atlantic coasts, France | Phuong et al., 2017 |
| Oyster (*Saccostrea cucullata*) | 1.5–7.2 | Particles/g | Pearl River Estuary, China | Li et al., 2018 |
| Oyster (*Saccostrea cucullata*) | 1.4–7.0 | Particles/g | Pearl River Estuary, China | Li et al., 2018 |
| Oyster | 0.11–2.25 | Particles/g | China | This study |
predominant size of microplastics was in the range of 5 to 10 μm in muscles and 11 to 20 μm in oysters. Phuong et al. (2017) found that microplastics larger than 100 μm in size accounted for only 11% of the total particles in muscles, whereas they account for 32% of the total microplastics in oysters. These variations in size distributions of microplastics in bivalves could be attributed to the size of the ingested particles in different bivalve species and the local environmental microplastic contamination. Oysters are larger in size, and they also have larger gills and lip pulps, which may result in the possibility of taking up larger particles than mussels (Cognie et al., 2003).

5. Conclusions

This study comprehensively investigated microplastic bioavailability in cultured oysters along the coastal areas of China. This study provided quantitative and qualitative results concerning the microplastics uptake of the cultured oysters from 17 sites along the coastline of China. Our results indicated the widespread existence of microplastics in cultured oysters with an average microplastics uptake rate of 84%. The average abundance of microplastics was 0.62 items/g (wet weight) or 2.93 items/individual in oysters. Fibers constituted the majority of the shapes; cellulose, PE and PET were the predominant polymeric types. Our results suggest that microplastics might pose potential risks to human health when humans consume these contaminated oysters. In addition, long-term and more complex assessments in marine organisms for monitoring purposes around the world are suggested to ensure the safety of environmental and human health.

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