Science of the Total Environment 742 (2020) 140525

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Composition, spatial distribution and sources of plastic litter on the East China Sea floor

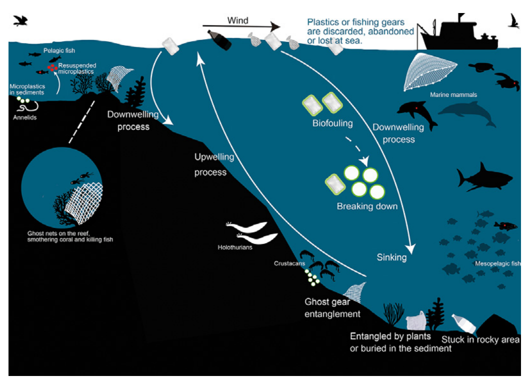
Feng Zhang [a,c,d], Chenyang Yao [b], Jiayi Xu [a,c,d], Lixin Zhu [a,c,d], Guyu Peng [a,c,d], Daoji Li [a,c,d,*]

[a] State Key Laboratory of Estuarine and Coastal Research, East China Normal University, 200062 Shanghai, China
[b] Merchant Marine College, Shanghai Maritime University, Shanghai 201306, China
[c] Plastic Marine Debris Research Center, East China Normal University, 200062 Shanghai, China
[d] Regional Training and Research Center on Plastic Marine Debris and Microplastics, IOC-UNESCO, Shanghai 200241, China

HIGHLIGHTS

- A total of 222 plastic items corresponding to 6.04 kg is collected from the East China Sea floor.
- Marine plastic litter density varied along the East China Sea Coast.
- Use of plastic data collected in seabed via bottom trawls.
- The mean density of plastic litter on the sea floor was 375.44 items/km^2 (9.64 kg/km^2).
- 95% of the 43 monitoring trawls contained plastic litter and fishing gear was the dominating source.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 7 May 2020
Received in revised form 22 June 2020
Accepted 24 June 2020
Available online 30 June 2020

Editor: Damia Barcelo

Keywords:
Chemical composition
East China Sea
Plastic pollution
Seafloor

ABSTRACT

Plastics are present in all marine waters around the globe, often at high abundances and they are potentially harmful to marine organisms. In this study, we investigated the regional distribution, composition, and abundance of plastic items on the floor of the East China Sea based on 43 bottom trawl samples collected during 2019. Considerable geographical variation was detected. Polyethylene was the most abundant polymer type where it accounted for 42.83% by weight. The surface areas and lengths of the plastic items ranged from 3.43 to 2842 cm^2 and from 1.3 cm to 14.23 cm, respectively. The plastic density was 18.94 kg/km^2 in Sanmen Bay but it was significantly lower at 2.24 kg/km^2 in Wenzhou Bay. Fishing gear represented 23.87% of the plastic items. The plastic items found on the coastal sea bed were probably transported and moved during upwelling and downwelling processes, and finally deposited on the seafloor due to the effect of biofouling. The accumulation of macro- and mesoplastics could have detrimental impacts on seafloor ecosystems.

1. Introduction

The global production of plastics increased from 1.5 million tons in 1950 to 348 million tons in 2018 (Lebreton et al., 2018; Europe, 2016; Aisbl, 2018). Plastic litter (including microplastic) is a new addition to the list of global threats, which includes climate change, ocean acidification, and ozone depletion (Amaral-Zettler et al., 2015; UNEP, 2015).

* Corresponding author at: State Key Laboratory of Estuarine and Coastal Research, East China Normal University, Shanghai 200062, China.
E-mail addresses: 51173904028@stu.ecnu.edu.cn (F. Zhang), yaochenyang@stu.shmtu.edu.cn (C. Yao), jyxu@sklec.ecnu.edu.cn (J. Xu), lixinzhu0305@hotmail.com (L. Zhu), guyu_peng@hotmail.com (G. Peng), daojili@sklec.ecnu.edu.cn (D. Li).

https://doi.org/10.1016/j.scitotenv.2020.140525
0048-9697/

Plastics are convenient but they pose a significant environmental threat to marine systems and they have become an issue of public concern. There are gaps in our knowledge regarding the spatial patterns, weights, and types of marine litter in the China Sea, thereby requiring the development of a coordinated regional monitoring program in these waters. Eriksen et al. (2014) estimated that a minimum of 2.25 trillion plastic particles weighing 268,940 tons are floating at sea. Plastic debris derived from sea-borne sources (fishing activity) and land-borne sources has accumulated in the open sea (Cózar et al., 2014) and oceanic gyres (Eriksen et al., 2013; Law and Peacock, 2010; Moore et al., 2001), as well as in the deep sea (Peng et al., 2020), terrestrial environments (Duis and Coors, 2016), and freshwater environments (Eerkes-Medrano et al., 2015). The distribution of this plastic debris is influenced by the buoyancy of plastics and their slow biodegradation rate (Sudhakar et al., 2007). Data acquired by continuous plankton recorders have demonstrated that fisheries are major sources of plastic pollution (Ostle et al., 2019). A large zone where buoyant plastic accumulates was observed between California and Hawaii, and it is known as the "great Pacific garbage patch" (Boerger et al., 2010; Lebreton et al., 2018).

Plastic pollution is hazardous to sea turtles (Wilcox et al., 2013), sea birds (Tanaka et al., 2013), marine mammals (Besseling et al., 2015), and fish (Jabeen et al., 2017; Zhang et al., 2019a, 2019b), where these hazards include physical threats (entanglement in loops or plastic bags) and physiological damage (ingestion of small plastic debris). Entangled animals lose their ability to catch food or avoid predators, and they can become impaired or suffocated. Ingested plastic may block the digestive tract, damage the stomach lining, or cause poisoning due to toxic chemicals or microorganisms leaking from the plastic debris (Jiang et al., 2018; Mato et al., 2001). The local environment can also be threatened because of invasions by marine life carried on lightweight plastic debris. These animal-plastic combinations may be transported by ocean currents and winds, and transfer organisms to non-native habitats, thereby posing a threat to the biodiversity in coastal environments. Colonization by alien species is a major threat to global biodiversity. Barnes David (2002) reported that many types of animals use marine debris as a mobile home, but particularly bryozoans, barnacles, polychaete worms, hydroids, and mollusks. Jiang et al. (2018) demonstrated that microbial communities could colonize the surfaces of microplastic particles in intertidal environments around the Yangtze River estuary.

In contrast to floating litter, the litter on the seafloor tends to become trapped in areas with high accumulations of sediment. Plastics that reach the seabed may have been transported there over a considerable distance (Galgani et al., 2000; Keller et al., 2010; Pham et al., 2013; Ramirez-Llodra et al., 2013; Watters et al., 2010). The densities, fouling processes, sizes, and shapes have important effects on the transport distance and sedimentation rate for plastic materials (Buhl-Mortensen and Buhl-Mortensen, 2017; Woodall et al., 2015). Some studies have determined the degree of plastic pollution in the East China Sea. In particular, the Communique of the State of Marine Ecology and Environment in China (2018) noted that the average number of litter pieces on the seabed was 1031 pieces/km^2. Plastic was the largest contributor to the litter where it accounted for 88.2% of the total, and the litter density decreased from 127 kg/km^2 in 2012 to 18 kg/km^2 in 2018. Lee et al. (2006) surveyed the marine litter on the seabed in the East China Sea using a bottom trawler during 1996–2005. Recent research has focused on pollution with microplastics in the East China Sea (particles <5 mm in size) because of their prevalence in the ocean and potential ecological effects. The first step required to understand and alleviate the problem of marine plastic debris involves quantifying the existing amounts. Thus, the aim of the present study was to determine the composition and spatial distribution of plastic on the seabed, and to conduct a risk assessment for the seafloor environment in the East China Sea. Identifying the sources of marine plastic pollution is essential for establishing methods to reduce marine plastic litter. The information obtained in this study will hopefully improve marine governance, awareness, and ecosystem health. Therefore, determining where plastic accumulates and its availability for incorporation into the food chain is fundamental for understanding threats to deep seafloor ecosystems around the world (Thurber et al., 2014).

2. Materials and methods

2.1. Study area and data collection

Data obtained from five study areas comprising the Zhoushan Islands (ZS), Xiangshan Bay (XS), Sanmen Bay (SM), Taizhou Bay (TZ), and Wenzhou Bay (WZ) were used to identify the characteristic distributions of plastic debris deposits on the seafloor (Figs. 1 and 2). Five surveys were conducted by the common fishing ship No. 04126 *Zhepuyu* from May to September during 2019 in the East China Sea (Figs. 1 and 2; details of surveys are shown in Table S1). Bottom trawl nets were used to collect marine plastic from the seabed. The survey method was conducted in accordance with the Specifications for Oceanographic Survey (GB12736-2007). The bottom trawl employed a 32 m-long net with a mesh that became progressively smaller, ranging from 18.0 to 2.2 cm, which is an effective method for the large-scale evaluation and monitoring of seafloor litter due to the control of the mesh size and opening width of the trawl (Galgani et al., 2013; Goldberg, 1994). During sampling, the fishing boat maintained a speed of about 3.0 knots/h. Information about the cruises and trawling station is provided in Fig. 1 and Table S1.

All plastic items were retained, labeled with station information, and frozen, apart from three large items comprising a buoyant ball and two crab traps, which were examined on board the ship.

2.2. Laboratory analysis and quality control

The collected plastic debris was processed to remove adhesive impurities. Samples were washed with dishwashing liquid, followed by Milli-Q water, and then dried in an electric thermostatic drying oven (DGG-9070A, China) for 2 h at 60 °C. Before recording their weights (g), the samples were wiped again with delicate task wipers (KIMTECH34155, USA) to remove any sediments. The surface area and length of each plastic item were measured with Vernier calipers (Mitutoyo, Japan). The chemical composition of the plastic debris was identified by Fourier transform-infrared (FT-IR) spectroscopy in the attenuated total reflection mode (Thermo Fisher Nicolet iS5). The mid-infrared wavelength range (4000–675 cm^{-1}) was used to co-scan each sample 64 times at a resolution of 8 cm^{-1}. Calibration was conducted based on the ambient carbon dioxide and water vapor levels before analysis to correct for background interference. The spectra were then analyzed using the OMNIC 9 software package and evaluated with the OMNIC spectra library. Plastic items with a high level of certainty (matching degree with reference spectra higher than 80) were accepted. The litter categories were defined according to a previously described approach (Cheshire et al., 2009; Galgani et al., 2013) that considers the specificity of the seafloor.

2.3. Data treatment: mapping, composition, and analysis

Records of plastic litter obtained from bottom trawls were used to prepare geographic information system maps of the litter distribution in the East China Sea. Fig. 2 was prepared using land maps from Google Earth with ArcGIS 10.2. The plastic density (De) was plotted to indicate the areas of occurrence and distribution. The area (A) of each sampling transect was obtained by multiplying the transect length (L) calculated based on the starting position and end position of trawling by the width (W) of the trawl net according to the following equation.

$$A = \mathrm{Lati}\left(km^2\right) \tag{1}$$

The plastic density was calculated as the ratio between the weight of plastic debris (M) relative to the sampling area (A) using the following equation.

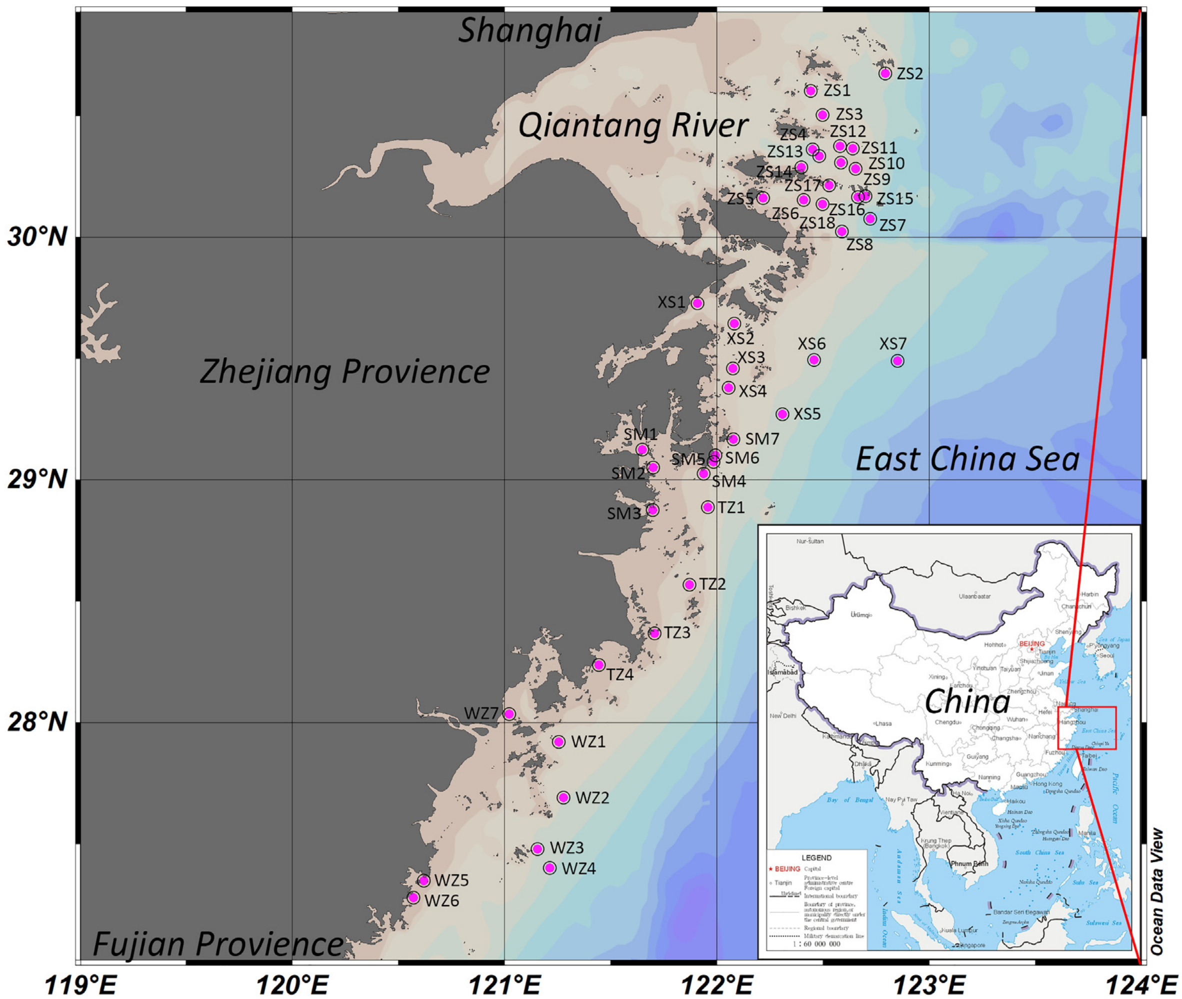


Fig. 1. Five study areas in the East China Sea comprising the Zhoushan Islands (ZS), Xiangshan Bay (XS), Sanmen Bay (SM), Taizhou Bay (TZ), and Wenzhou Bay (WZ).

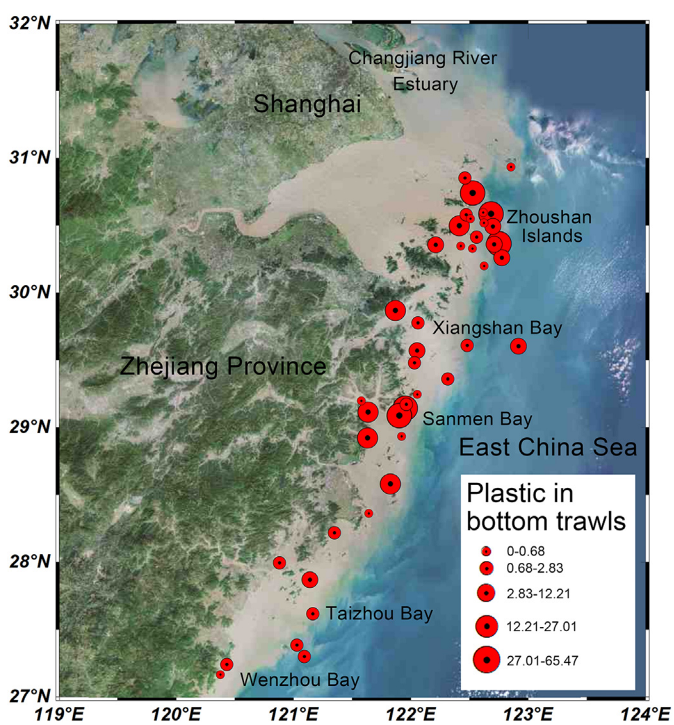


Fig. 2. Density of plastic pieces on the floor of the East China Sea (unit: kg/km^2).

$$\mathrm{De} = \frac{M}{A}\left(\mathrm{kg}/km^2\right) \tag{2}$$

We modeled the upwelling regions during the months when sampling was conducted and the detailed modeling method is provided in the Supporting information.

Statistical tests were conducted using the IBM SPSS® software platform (version 22.0) and R 3.4.3. Significant differences between regions were calculated using the *t*-test for independent samples. Analysis of variance (ANOVA, generalized linear model) was employed to examine differences in density among regions. Linear correlation analysis was conducted to examine the relationships between the plastic density and distance from the coast for the sampling points (using Spearman's correlation coefficients). An α level of 0.05 was used in all tests. Unless indicated otherwise, data are reported as the mean ± standard deviation.

3. Results

3.1. Spatial distribution and composition of plastic debris

In total, 222 items and 6.04 kg of marine litter were collected in 43 monitoring hauls from part of the study area measuring 0.58 km^2. Plastic debris was found in 95.35% of all the bottom trawl nets, where fishing gear comprised 56.06% of all the pieces by weight and film accounted for 31.53% of the items (Table 1). The highest concentrations of total plastic pieces were recorded at sites ZS10 and SM5 (Fig. 2), and the

Table 1
Compositions and proportions of plastics by categories.[a]

Category/subcategory	Weight (g)	Percentage of total amount	Items	Percentage of total plastics
Fishing gear				
Fishing line	337.87	5.60	24	10.81
Fishing net	1773.55	29.38	13	5.86
Crab trap	635.13	10.52	2	0.90
Other fishing related	637.34	10.56	5	2.25
Bottle	161.97	2.68	9	4.05
Bag	879.07	14.56	8	3.60
Cable tie	6.77	0.11	3	1.35
Container	24.78	0.41	2	0.90
Lid	4.16	0.07	4	1.80
Sheet	1243.82	20.61	40	18.02
Food wrapper	208.54	3.45	23	10.36
Wrapper	85.32	1.41	18	8.11
Other (unclassified)				
Film	35.37	0.59	70	31.53
Foam[a]	2.40	0.04	1	0.45

[a] Foam plastic was packaged in a plastic bag.

concentration decreased toward the south. The mean density of plastic litter in the entire area was 375.44 items/km^2 (9.64 kg/km^2).

The densities of marine litter differed significantly among regions (ANOVA, $p < 0.05$). The maximum mean plastic litter densities over all of the cruises listed in Fig. 2 were found at SM5 (2333.41 items/km^2 and 54.55 kg/km^2), followed by SM4 and ZS3 (1316.35 items/km^2 and 39.59 kg/km^2, and 1309.73 items/km^2 and 50.23 kg/km^2, respectively). The lowest mean litter densities were detected at ZS14 and ZS12 (71.26 items/km^2 and 0.02 kg/km^2, and 79.16 items/km^2 and 0.02 kg/km^2, respectively). However, there were no significant differences in the plastic densities and the distances from the coast for the sampling points ($p > 0.05$). There were no significant differences in the depth ranges for any of the types of plastic debris ($p > 0.05$).

3.2. Sources and characteristics of marine plastic litter

Plastic items were identified and assigned to the 10 categories presented in Table 1. Fig. 3 shows the rankings of all the plastic litter collected from the seafloor in the East China Sea. These rankings are based on the percentages of each particular category among the total plastic debris, where the percentages of plastic litter were evaluated in terms of the number of items and weight. Analyzing the specific sources of litter can indicate the differences between land-based and marine-based plastic, and this was reflected in the definitions of the categories. Fishing gear was the dominant type of debris in the five sea areas sampled, where the weight of this litter type comprised >50% of the total, followed by sheets (up to 20%) and bags (14.56%) (Fig. 3, Table 1). The litter items in the "other" category were present at small percentages by weight and their uses could not be recognized (Fig. S1A). Lost nets and lines were the most common items within the "fishing gear" category (Table 1, Fig. S1A). Two crab traps and one buoyant ball were collected from ZS13 and ZS17, and TZ2, respectively. The buoyant ball and other components of crab traps were classified into the "other fishing related" subcategory. The largest variety of plastic items was found at SM5 (Fig. 2) and the highest proportion of fishing gear at SM4 (Fig. 2).

Fishery related plastic litter was ranked as follows in terms of weight and the number of items (in brackets): 1 (six), fishing net; 4 (nine), other fishing related; 5 (13), crab trap; and 6 (three), fishing line. Plastic fishing net was the largest subcategory of fishery related litter and it was the sixth most abundant in terms of the number of items (Fig. 3).

The surface area calculations for plastic bags, packing debris, and fishing nets showed that medium sized items measuring <100 cm^2 comprised 50% of the total and the items measuring between 100 cm^2 and 1000 cm^2 accounted for 40.63%. The calculated lengths of fishing lines and other synthetic ropes ranged from 1.3 cm to 14.23 cm.

3.3. Identification of plastics using FT-IR

The chemical composition of each piece of plastic debris was identified using FT-IR spectroscopy and compared with OMNIC libraries. In total, 10 polymer types were identified as polyethylene (PE), polycarbonate (PC), polyethylene terephthalate (PET), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), and three copolymers comprising acrylonitrile butadiene styrene copolymers (ABS), PE/PC copolymers, and PP/PE copolymers. The FT-IR spectra obtained for the most prevalent polymer types are shown in Fig. 4. PE was the most abundant polymer type where it accounted for 42.83% by weight (27.93% in terms of items). The proportions of PVC, PET, and ABS decreased in order by weight (Fig. 5).

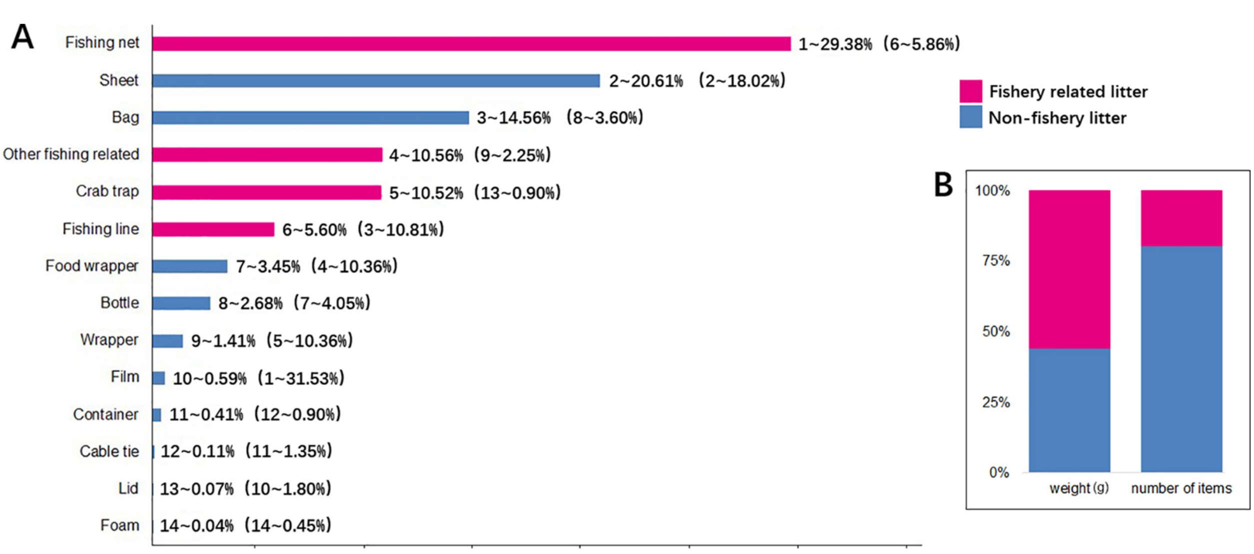


Fig. 3. Rankings of the plastic litter categories (A) in terms of weight and the number of items (in brackets). Proportions of fishery-derived litter in marine plastic litter in terms of the number of items and weight (B).

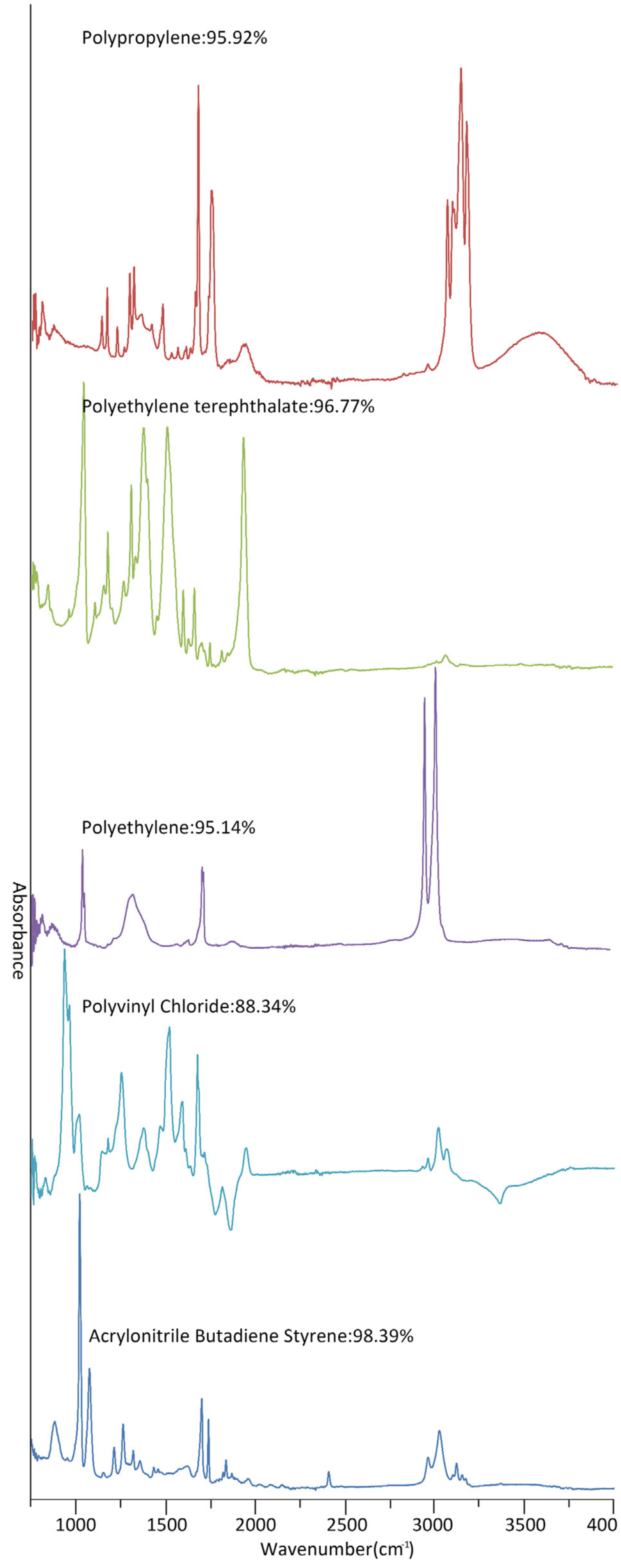


Fig. 4. Infrared spectra and matching degrees for the most frequently observed particles. IR spectra from top to bottom: polypropylene, polyethylene terephthalate, polyethylene, polyvinylidene chloride, and acrylonitrile butadiene styrene.

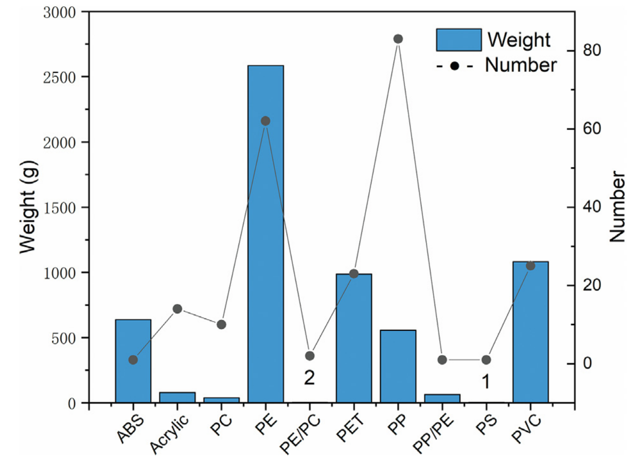


Fig. 5. Weights and numbers of different plastic polymers collected from the seafloor in the East China Sea.

4. Discussion

4.1. Categories, spatial distribution, and sources of plastic litter

In this study, we conducted the first systematic survey of plastic litter on the seafloor in the East China Sea. Large numbers of plastic particles have been found in seabed environments in previous studies (Grøsvik et al., 2018; Ioakeimidis et al., 2014; Koutsodendris et al., 2008; Olguner et al., 2018; Pham et al., 2014). The plastic pollution along the coastline of east China was at an intermediate level (Table 2). The densities of marine plastic litter found in the present study were significantly lower than those found on the seafloor in the Gulf of Alicante (Spanish Mediterranean) using bottom trawls (García-Rivera et al., 2017), where the average density was 34 ± 4 kg/km^2 and the maximum density was 171 ± 36 kg/km^2. Our results corroborate the results obtained by Lee et al. (2006) who found that the abundance of plastic litter was higher in the north East China Sea one decade ago (30.6 kg/km^2). The reduction in marine plastic litter from the land to the ocean may be attributed to the enforcement of policies and regulations related to the management of plastic in China. Similarly, a significant decreasing trend was observed in the coastal waters of the Wadden Sea in the southern North Sea, possibly due to the recent decline in coastal fisheries in the North Sea (Schulz et al., 2015). However, in some areas around Greece, the abundance of litter at depth on the seafloor increased over a period of 8 years (Koutsodendris et al., 2008). Neves et al. (2015) demonstrated that the highest plastic litter density (178.9 ± 64.0 items/km^2) was found at the mouth of the Tagus River due to the high population density in the Lisbon metropolitan area and inputs from the large river basin. It has been reported that Mediterranean Sea is among the areas throughout the world impacted most by all types of marine litter (Table 2; Spedicato et al., 2019). These variations in previously reported plastic litter densities are probably due to differences in parameters such as the location, collection method, coastal population, marine traffic, and fishing activity (Kammann et al., 2018). Trawl fisheries are likely to underestimate the number of litter items because small particles are not caught by the net, which has a mesh size of 20 mm at the cod-end. Stony areas that are not accessible to trawling might offer more insights and they could be explored using alternative methods (e.g., remotely operated vehicles or divers). Data regarding small litter particles collected from the seafloor, images obtained by divers or remotely operated vehicles, and the litter consumed by marine organisms should ideally be combined (Tubau et al., 2015). Furthermore, comparing studies is difficult due to the inconsistent units employed (Table 2).

In the present study, the most polluted areas were ZS and SM, which are popular tourist attractions. Deng et al. (2018) stated that the annual volume of fishery related plastic (1.09 × 10^4 t/a) that entered the sea was much higher than that derived from beach tourism (1.17 × 10^3 t/a).

Based on the annual amount of 0.13 to 640,000 tons of commercial fishing gear discarded worldwide, the contribution of discarded fishing nets to marine plastic garbage cannot be ignored (Assessing potential ocean pollutants: a report of the Study Panel on Assessing Potential

Table 2
Densities of plastic and fishing gear among benthic marine litter worldwide.

No.	Study area	litter density	Fishing gear	Plastic	Sampling method	Reference
1	Adriatic Sea	85 ± 26[a]	30.6[a,*]	34 ± 4[b]	Rapido trawl	Strafella et al., 2015
2	Antalya Bay, Mediterranean	18.5–2186[b] 115–2762[a]	–	93.27–2239.98[a], 15.00–1772.85[b]	Conventional bottom trawl	Guven et al., 2013
3	Baltic Sea North Sea	5.07[a] 16.8[a]	0.3[a,*] 5.57[a,*]	3.35[a] 13.94[a]	Trawl	Kammann et al., 2018
4	Barents Sea, Norway	230[a] 174[b]	102-149[a]	9-12[a]	Tethered video platform "Chimera"	Buhl-Mortensen and Buhl-Mortensen, 2017
	Norwegian Sea, Norway	678[a] 601[b]	120-200[a]	21-179[a]		
5	Barents Sea, Norway	772[c]	–	2.9[b]	Campelen 1800 shrimp trawl	Grøsvik et al., 2018
6	Coast of Portugal	17.3 ± 12.8 to 78.7 ± 47.7[a]	–	49.5 ± 9.3[a]	Bottom trawl	Neves et al., 2015
7	ICES subdivisions[***]	1.01[d] 2.87[e]	0.02–0.06[d] 0.06–0.16[e]	0.35[d] 1.00[e]	Large standard trawl	Zablotski and Kraak, 2019
8	Leeward Dutch Caribbean	2700[a]	432[a]	972[a]	Johnson Sea Link II	Debrot et al., 2014
9	Mediterranean	0.02–3265[b]	–	0.02–2612[b]	Otter-trawl Maireta system and Agassiz trawl	Ramirez-Llodra et al., 2013
10	Mediterranean	0.01–5.85[d]	0.0007–0.41[d]	0.0073–4.27[d]	Trawl	Eryaşar et al., 2014
11	Mediterranean	97 ± 78[a]	–	45.59[a]	IFREMER GOC 73 otter trawl	MIFSUD et al., 2013
12	Mediterranean and Black Sea	24–1211[a]	–	10.85–1150.45[a]	Trawl	Ioakeimidis et al., 2014
13	Mediterranean	1559–15057[a]	263.47–2544.63[a]	1125.60–10,871.15[a]	Remotely operated vehicle	Tubau et al., 2015
14	Mediterranean, French, the canyon	0.27–7.60[a]	0.08–2.24[a]	0.07–1.98[a]	Bottom trawl	Gerigny et al., 2019
	Mediterranean, French, the continental shelf	29.32–459.75[a]	1.17–27.59[a]	19.94–335. 62[a]		
15	Mediterranean, Spanish	22.50[b]	6.56[b]	17.08[b]	Bottom trawl	García-Rivera et al., 2017
16	Mediterranean , Antalya Bay, Turkey	13.3–651.1[a] 0.02–559[b]	–	9.59–569.44[a]	Conventional bottom trawl	Olguner et al., 2018
17	Mediterranean, Greece	72–437[a] 6.7–47.4[b]	6.48–39.33[a] 0.60–4.27[b]	40.32–244.72[a] 3.375–26.54[b]	Trawl	Koutsodendris et al., 2008
18	Mediterranean, Spanish	9.8 ± 42.9[b]	–	2.87[b]	Bottom trawl	García-Rivera et al., 2018
19	Northwest Pacific, Ryukyu Trench	1200–7100[a], 7.5–121.4[b]	–	–	ORE-type beam trawl[****]	Shimanaga and Yanagi, 2016
20	Southern Baltic	0–2.23[e] 0.20 ± 0.30[e]	0–0.14[e]	0–1.27[e]	Trawl	Urban-Malinga et al., 2018
Present study	East China Sea	–	210.47[a] 5.40[b]	375.44[a] 9.64[b]	Bottom trawl	

[a] Items/km^2.
[b] kg/km^2.
[c] g/haul.
[d] kg/haul.
[e] Items/haul.
[*] Fishing gear classified as plastic.
[***] ICES means International Council for the Exploration of the Sea.
[****] ORE beam trawl are common research sampling gears for deep-sea biodiversity (Tsai et al., 2009).

Ocean Pollutants to the Ocean Affairs Board, Commission on Natural Resources, National Research Council, 1975; Merrell, 1980; Martin et al., 2016). The main component of the marine plastic litter collected in the present study was fishing gear, which is consistent with other studies (van den Beld et al., 2017). In the present study, the proportion of fishery related litter in terms of the number of items caught was small in the different sea areas, but the proportion was high in terms of weight. The weight of fishing gear comprised 90% of the total in the TZ area where we collected a lost crab trap. A wide range of fishery related litter proportions have been reported around the world (Kammann et al., 2018; Urban-Malinga et al., 2018; Vieira et al., 2015). Most of the plastics that cause entanglement appear to be monofilament lines, ropes, and other types of fishing related gear that enter the water near coastal cities and due to commercial fishery activities (Laist, 1997). Kammann et al. (2018) collected plastic litter via bottom trawls and reported that fishing line, synthetic rope, and sheets were the most common types on the seafloor in the North Sea and Baltic Sea. In the present study, the number of land-based plastic litter items (non-fishery litter) exceeded 80% of the total plastic litter but only 43% of the plastics by weight (Fig. 3). Most of the non-fishery litter items were general waste that could not be readily assigned to land- or ship-based sources, including domestic, agricultural, and industrial activities. In our survey, we collected disposable plastic items (land-based) that mainly comprised sheets, bags, food wrappers, and other containers. Whiting (1998) suggested that glass bottles could be attributed to merchant ships, commercial vessels, and recreational boats, thereby indicating that they have marine-based sources. Marine litter is a major problem and it should be strictly prevented by limiting land-based pollutants, supporting recycling, and implementing improved waste management before it reaches a marine environment. However, further research is required to determine the amount of fishery litter that originates from recreational fisheries and the proportions of different litter categories discarded by these sources.

4.2. Chemical composition and transport of plastic litter

PE was the most frequent plastic type in our study because it has a wide range of uses (Table S2), including fishery related (fishing lines, fishing nets, etc.) and non-fishery related (food wrapper, bags, etc.) applications. A buoyant ball collected from ZS13 was identified as ABS and it weighed 637.34 g. ZS is one of the largest fishing areas in China and fishing activity is frequent. The buoyant ball may have been abandoned, lost, or otherwise discarded. Comparing the polymer types determined in this study and other investigations was difficult because there is no single and widely accepted litter categorization protocol, and no previous studies have demonstrated how to identify the chemical composition of plastic litter.

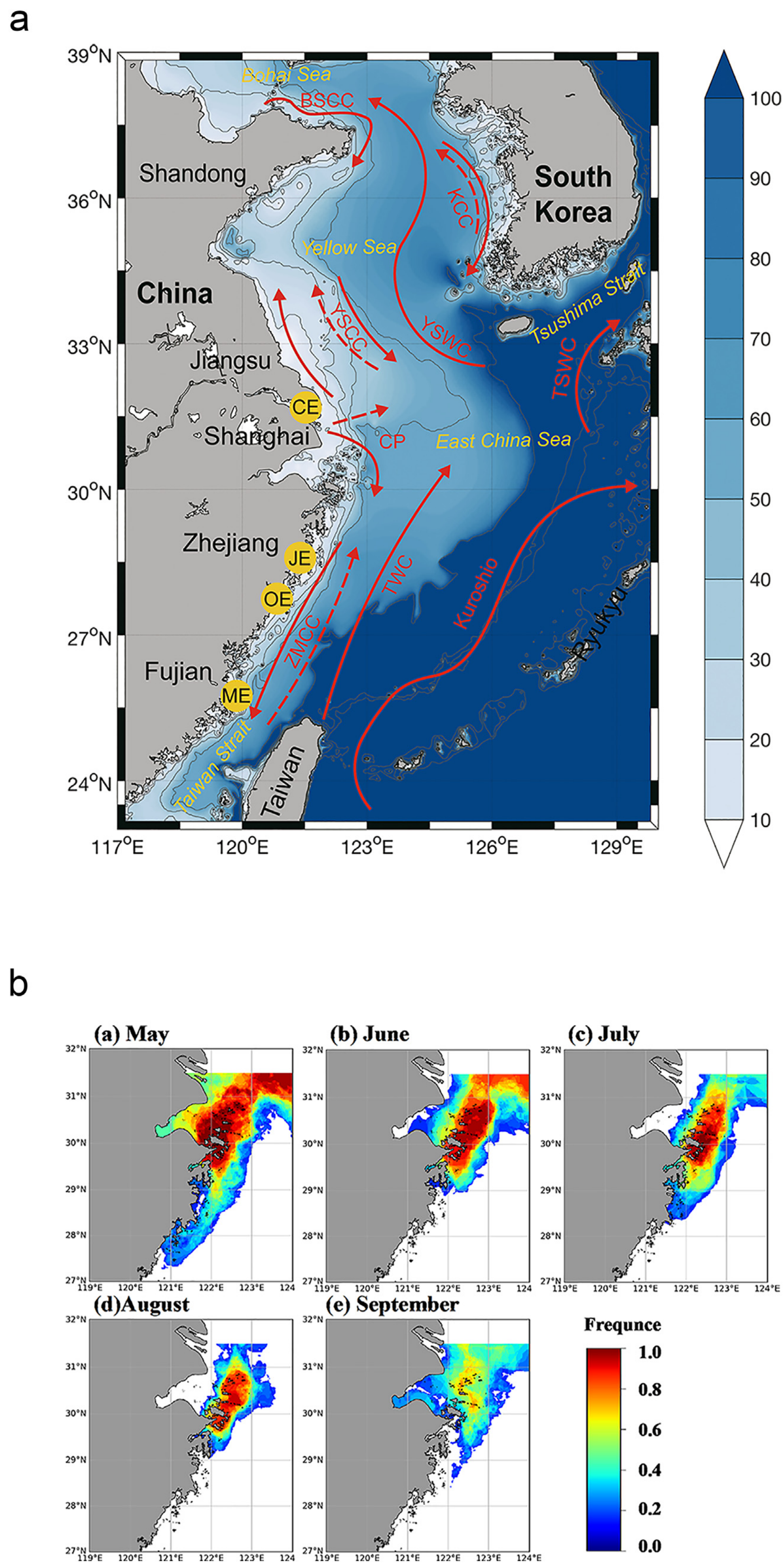


Fig. 6. (A) Schematic map of Bohai Sea (BH), Yellow Sea (YS), East China Sea (ECS), and adjacent seas. Abbreviations denote the following: Changjiang River Estuary (CE), Minjiang River Estuary (ME), Oujiang River Estuary (OE), and Jiaojiang River Estuary (JE). Solid arrows indicate the Taiwan Warm Current (TWC), Tsushima Warm Current (TSWC), Yellow Sea Warm Current (YSWC), Yellow Sea Coastal Current (YSCC), Changjiang River plume (CP), Zhejiang and Fujian Coastal Current (ZMCC), Bohai Sea Coastal Current (BSCC), and Korean Coastal Current (KCC). The dashed arrows represent the summer states of KCC, ZMCC, CP, and YSCC. The color bar indicates the depth of the water. (B) Cumulative frequency of upwelling regions in East China Sea.

However, the differences between the chemical compositions of plastics and microplastics are significant. Zhang et al. (2019b) collected sediment samples from the East China Sea off the coast of China and showed that the dominant chemical component of the microplastics was PET. Peng et al. (2017) examined estuarine sediment samples from the Changjiang River Estuary and found that 97% of the microplastics were major components of clothes, such as rayon and polyester.

In the present study, most of the plastics detected had lower densities than seawater, such as PC, PE, PET, PP, and PS. Intuitively, it is expected that polymers such as PS with a greater density than seawater will occur on the seabed, but lower density polymers such as PE and PVC were also present. The densities of the plastic items detected are listed in Table S2. Physical (oceanographic zones and wind mixing) and biological (biofouling) processes can explain why the light plastics lost their buoyancy and ultimately settled on the seafloor.

Many strong surface currents occur along the coastline of the East China Sea, as shown in Fig. 6A. Upwelling and downwelling also occur in the largest fishing area (ZS) (Fig. 6B). We propose that plastic debris is often transported horizontally by the wind and then transported vertically via downwelling processes in a physical manner. We modeled the upwelling region during the sampling period (Method in supporting information). There was a significant monthly change in the upwelling along the Zhejiang coast, which was affected mainly by the monsoon (Hu and Wang, 2016) in May, before strengthening in June, peaking in July and August, and then decreasing until it disappeared in late September, as shown in Fig. 6A. The upwelling is mainly distributed in the coastal waters near ZS. The upwelling occurs in the form of a north-south band, and the areas other than the upwelling are downwelling, which could possibly transport plastic from the sea surface to the seabed. Biofouling can cause large plastic objects to sink during their transport. The surfaces of floating plastic debris can be colonized by microbes, thereby making the debris sink (Hadfield et al., 2014; Mincer et al., 2016; Oberbeckmann et al., 2014). Biofouling is defined as the accumulation of organisms on submerged surfaces, and it affects the hydrophobicity and buoyancy of plastic (Carpenter and Smith, 1972; Zettler et al., 2013). Ye and Andrady (1991) demonstrated that most plastics undergo fouling, which makes them negatively buoyant and they eventually sink in seawater. However, biofouling is a complex phenomenon (Callow and Callow, 2002) that is influenced by the season, geographic location (proximity to propagule sources), water temperature, nutrient levels, substrate type, and the velocity and turbulence of the surrounding water flow (Fazey and Ryan, 2016). Simulation experiments will be conducted in a future study to determine the settlement rate and related factors for different types of plastic litter.

5. Conclusion

Considerable amounts of plastic litter are present on the seafloor. The mean density of plastic litter on the floor of the East China Sea was 375.44 items/km^2 (or 9.64 kg/km^2). We determined the spatial distributions and sources of plastic debris on the floor of the East China Sea. FT-IR spectroscopy was applied for the first time to identify the chemical compositions of the plastic items collected. PE was the most prevalent plastic type by weight, followed by PVC, PET, and PP. These results are consistent with the widespread usage of PE in fishery and non-fishery related activities. The surface areas and lengths of the plastic items ranged from 3.43 to 2842 cm^2 and from 1.3 cm to 14.23 cm, respectively.

Fishing activity is a notable source of pollution in the East China Sea and land-based plastics (sheets and bags) are also transported before settling on the seafloor. Long-term monitoring of marine litter on the seafloor is essential for understanding the trends in the plastic litter density over time and for assessing the effectiveness of litter reduction measures. Furthermore, determining the transport and fate of plastic litter, including microplastic, on the deep seafloor requires more in-depth and detailed research.

CRediT authorship contribution statement

Feng Zhang: Investigation, Formal analysis, Writing - original draft. **Chenyang Yao:** Methodology, Software. **Jiayi Xu:** Writing - review & editing. **Lixin Zhu:** Writing - review & editing. **Guyu Peng:** Writing - review & editing. **Daoji Li:** Writing - original draft.

Declaration of competing interest

The authors and co-author declare that there is no actual or potential conflict of interests regarding the publication of this article.

Acknowledgments

This study was funded by the National Key Research and Development Program (No. 2016YFC1402205), the National Natural Science Foundation of China (No. 41676190), and the "Future Scientist" PhD Incubation Program from East China Normal University to Guyu Peng. We thank the crew on the fishing boat No. 04126 *Zhepuyu*. In addition, we would like to thank the editor and anonymous reviewers for their useful comments on the manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2020.140525.

References

Aisbl, P., 2018. Plastics—The Facts 2018 an Analysis of European Plastics Production, Demand and Waste Data.

Assessing potential ocean pollutants: a report of the Study Panel on Assessing Potential Ocean Pollutants to the Ocean Affairs Board, Commission on Natural Resources, National Research Council. (Chapter 8). 1975, 405–438.

Amaral-Zettler, L.A., Zettler, E.R., Slikas, B., Boyd, G.D., Melvin, D.W., ... Morrall, C.E., 2015. The biogeography of the plastisphere: Implications for policy. Front. Ecol. Environ. 13 (10), 541–546. https://doi.org/10.1890/150017.

Barnes David, K.A., 2002. Biodiversity invasions by marine life on plastic debris. Nature 416 (6883), 808–809.

Besseling, E., Foekema, E.M., Van Franeker, J.A., Leopold, M.F., Kühn, S., Bravo Rebolledo, E.L., et al., 2015. Microplastic in a macro filter feeder: humpback whale megaptera novaeangliae. Mar. Pollut. Bull. 95 (1), 248–252.

Boerger, C.M., Lattin, G.L., Moore, S.L., Moore, C.J., 2010. Plastic ingestion by planktivorous fishes in the North Pacific central gyre. Mar. Pollut. Bull. 60, 2275–2278.

Buhl-Mortensen, L., Buhl-Mortensen, P., 2017. Marine litter in the Nordic seas: distribution composition and abundance. Mar. Pollut. Bull. 125, 260–270.

Callow, M.E., Callow, J.A., 2002. Marine biofouling: a sticky problem. Biologist 49, 10–14.

Carpenter, E.J., Smith, K.L., 1972. Plastics on Sargasso sea-surface. Science 175 (4027), 1240–1241.

Cheshire, A.C., et al., 2009. UNEP/IOC guidelines on survey and monitoring of marine litter. 2009 UNEP Regional Seas Rpts & Studies, No. 186; IOC Tech. Ser. No. 83, pp. 257–270.

Cózar, A., Echevarría, F., Ignacio González-Gordillo, J., Irigoien, X., Úbeda, B., Hernández-León, S., et al., 2014. Plastic debris in the open ocean. Proc. Natl. Acad. Sci. U. S. A. 111, 10239–10244.

Debrot, A.O., Vinke, E., van der Wende, G., Hylkema, A., Reed, J.K., 2014. Deepwater marine litter densities and composition from submersible video-transects around the ABC-islands, Dutch Caribbean. Mar. Pollut. Bull. 88, 361–365.

Deng, T., Gao, J.M., Wu, W.N., Qian, Y.L., An, L.H., 2018. Study on the discharging characteristics of large plastic litters along Wenzhou coastal. China Environ. Sci. 38 (11), 4354–4360. https://doi.org/10.3969/j.issn.1000-6923.2018.11.046.

Duis, K., Coors, A., 2016. Microplastics in the aquatic and terrestrial environment: Sources (with a specific focus on personal care products), fate and effects. Environ. Sci. Eur. 28 (1), 1–25. https://doi.org/10.1186/s12302-015-0069-y.

Eerkes-Medrano, D., Thompson, R.C., Aldridge, D.C., 2015. Microplastics in freshwater systems: A review of the emerging threats, identification of knowledge gaps and prioritisation of research needs. Water Res. 75, 63–82. https://doi.org/10.1016/j.watres.2015.02.012.

Eriksen, M., Maximenko, N., Thiel, M., Cummins, A., Lattin, G., Wilson, S., et al., 2013. Plastic pollution in the South Pacific subtropical gyre. Mar. Pollut. Bull. 68, 71–76.

Eriksen, M., Lebreton, L.C.M., Carson, H.S., Thiel, M., Moore, C.J., Borerro, J.C., et al., 2014. Plastic pollution in the world's oceans: more than 5 trillion plastic pieces weighing over 250, 000 tons afloat at sea. PLoS One 9, e111913.

Eryaşar, A.R., Özbilgin, H., Gücü, A.C., Sakınan, S., 2014. Marine debris in bottom trawl catches and their effects on the selectivity grids in the north eastern Mediterranean. Mar. Pollut. Bull. 81, 80–84.

Europe, P., 2016. Plastics—the facts 2016. An analysis of European latest plastics production, demand and waste data. Available online. https://www.plasticseurope.org/

application/files/4315/1310/4805/plastic-the-fact-2016.pdf. (Accessed 7 August 2017). .
Fazey, F.M.C., Ryan, P.G., 2016. Biofouling on buoyant marine plastics: an experimental study into the effect of size on surface longevity. Environ. Pollut. 210, 354–360.
Galgani, F., Leaute, J.P., Moguedet, P., Souplet, A., Verin, Y., Carpentier, A., et al., 2000. Litter on the sea floor along European coasts. Mar. Pollut. Bull. 40 (6), 516–527.
Galgani, et al., 2013. Monitoring Guidance for Marine Litter in European Seas. MSFD GES Technical Subgroup on Marine Litter (TSG-ML). Final REPORT (120 pp).
García-Rivera, S., Lizaso, J.L.S., Millán, J.M.B., 2017. Composition, spatial distribution and sources of macro-marine litter on the Gulf of Alicante seafloor (Spanish Mediterranean). Mar. Pollut. Bull. 121, 249–259.
García-Rivera, S., Lizaso, J.L.S., Millán, J.M.B., 2018. Spatial and temporal trends of marine litter in the Spanish Mediterranean seafloor. Mar. Pollut. Bull. 137, 252–261.
Gerigny, O., Brun, M., Fabri, M.C., Tomasino, C., Le Moigne, M., Jadaud, A., et al., 2019. Seafloor litter from the continental shelf and canyons in French Mediterranean water: distribution, typologies and trends. Mar. Pollut. Bull. 146, 653–666.
Goldberg, 1994. Diamonds and plastics are forever? Mar. Pollut. Bull. 28, 466.
Grøsvik, B.E., Prokhorova, T., Eriksen, E., Krivosheya, P., Horneland, P.A., Prozorkevich, D., 2018. Assessment of marine litter in the barents sea, a part of the joint Norwegian–Russian ecosystem survey. Front. Mar. Sci. 5, 72.
Guven, O., Gulyavuz, H., Deval, M.C., 2013. Benthic debris accumulation in Bathyal grounds in the Antalya Bay, Eastern Mediterranean. Turk. J. Fish. Aquat. Sci. 13 (1), 43–49.
Hadfield, M.G., Nedved, B.T., Wilbur, S., Koehl, M.A.R., 2014. Biofilm cue for larval settlement in Hydroides elegans (Polychaeta): is contact necessary? Mar. Biol. 161 (11), 2577–2587.
Hu, J., Wang, X.H., 2016. Progress on upwelling studies in the China seas. Rev. Geophys. 54, 653–673.
Ioakeimidis, C., Zeri, C., Kaberi, H., Galatchi, M., Antoniadis, K., Streftaris, N., et al., 2014. A comparative study of marine litter on the seafloor of coastal areas in the Eastern Mediterranean and Black Seas. Mar. Pollut. Bull. 89, 296–304.
Jabeen, K., Su, L., Li, J., Yang, D., Tong, C., Mu, J., et al., 2017. Microplastics and mesoplastics in fish from coastal and fresh waters of China. Environ. Pollut. 221, 141–149.
Jiang, P., Zhao, S., Zhu, L., Li, D., 2018. Microplastic-associated bacterial assemblages in the intertidal zone of the Yangtze Estuary. Sci. Total Environ. 624, 48–54.
Kammann, U., Aust, M., Bahl, H., Lang, T., 2018. Marine litter at the seafloor – abundance and composition in the North Sea and the Baltic Sea. Mar. Pollut. Bull. 127, 774–780.
Keller, A.A., Fruh, E.L., Johnson, M.M., Simon, V., McGourty, C.M., 2010. Distribution and abundance of anthropogenic marine debris along the shelf and slope of the US West Coast. Mar. Pollut. Bull. 60, 692–700.
Koutsodendris, A., Papatheodorou, G., Kougiourouki, O., Georgiadis, M., 2008. Benthic marine litter in four Gulfs in Greece, Eastern Mediterranean; abundance, composition and source identification. Estuar. Coast. Shelf Sci. 77, 501–512.
Laist, D.W., 1997. Impacts of marine debris: entanglement of marine life in marine debris including a comprehensive list of species with entanglement and ingestion records. Marine Debris. Springer, New York, USA, pp. 99–139.
Law, K.L., Peacock, E.E., 2010. Plastic accumulation in the North Atlantic subtropical gyre. Science 329, 1185–1188.
Lebreton, L., Slat, B., Ferrari, F., Sainte-Rose, B., Aitken, J., Marthouse, R., et al., 2018. Evidence that the great pacific garbage patch is rapidly accumulating plastic. Sci. Rep. 8, 4666.
Lee, D., Cho, H., Jeong, S., 2006. Distribution characteristics of marine litter on the sea bed of the East China Sea and the South Sea of Korea. Estuar. Coast. Shelf Sci. 70, 187–194.
Martin, S., Jillian, H., Michael, S., 2016. A review of ghost gear entanglement amongst marine mammals, reptiles and elasmobranchs. Mar. Pollut. Bull. 111, 6–17.
Mato, Y., Isobe, T., Takada, H., Kanehiro, H., Ohtake, C., Kaminuma, T., 2001. Plastic resin pellets as a transport medium for toxic chemicals in the marine environment. Environ. Sci. Technol. 35, 318–324.
Merrell, T., 1980. Accumulation of plastic litter on beaches of Amchitka Island, Alaska. Mar. Environ. Res. 3 (3), 171–184. https://doi.org/10.1016/0141-1136(80)90025-2 In press.
Mifsud, R., Dimech, M., Schembri, P.J., 2013. Marine litter from circalittoral and deeper bottoms off the Maltese islands (Central Mediterranean). Mediterr. Mar. Sci. 14, 298–308.
Mincer, T.J., Zettler, E.R., Amaral-Zettler, L.A., 2016. Biofilms on plastic debris and their influence on marine nutrient cycling, productivity, and hazardous chemical mobility. Hazardous Chemicals Associated with Plastics in the Marine Environment.
Ministry of Ecology and Environment of the People''s Republic of China, 2018. Communique of the State of Marine Ecology and Environment in China. pp. 31–33.
Moore, C.J., Moore, S.L., Leecaster, M.K., Weisberg, S.B., 2001. A comparison of plastic and plankton in the north Pacific central gyre. Mar. Pollut. Bull. 42, 1297–1300.
Neves, D., Sobral, P., Pereira, T., 2015. Marine litter in bottom trawls off the Portuguese coast. Mar. Pollut. Bull. 99, 301–304.
Oberbeckmann, S., Loeder, M.G.R., Gerdts, G., Osborn, A.M., 2014. Spatial and seasonal variation in diversity and structure of microbial biofilms on marine plastics in Northern European waters. FEMS Microbiol. Ecol. 90 (2), 478–492.
Olguner, M.T., Olguner, C., Mutlu, E., Deval, M.C., 2018. Distribution and composition of benthic marine litter on the shelf of Antalya in the eastern Mediterranean. Mar. Pollut. Bull. 136, 171–176.
Ostle, C., Thompson, R.C., Broughton, D., Gregory, L., Wootton, M., Johns, D.G., 2019. The rise in ocean plastics evidenced from a 60-year time series. Nat. Commun. 10, 1622.
Peng, G., Zhu, B., Yang, D., Su, L., Shi, H., Li, D., 2017. Microplastics in sediments of the changjiang estuary, China. Environ. Pollut. 225, 283–290. https://doi.org/10.1016/j.envpol.2016.12.064.
Peng, G., Bellerby, R., Zhang, F., Sun, X., Li, D., 2020. The ocean's ultimate trashcan: Hadal trenches as major depositories for plastic pollution. Water Res. 168, 115121.
Pham, C.K., Gomes-Pereira, J.N., Isidro, E.J., Santos, R.S., Morato, T., 2013. Abundance of litter on Condor seamount (Azores, Portugal, Northeast Atlantic). Deep-Sea Res. II Top. Stud. Oceanogr. 98, 204–208.
Pham, C.K., Ramirez-Llodra, E., Alt, C.H.S., Amaro, T., Bergmann, M., ... Canals, M., 2014. Marine litter distribution and density in european seas, from the shelves to deep basins. Plos One 9 (4). https://doi.org/10.1371/journal.pone.0095839 e95839.
Ramirez-Llodra, E., De Mol, B., Company, J.B., Coll, M., Sardà, F., 2013. Effects of natural and anthropogenic processes in the distribution of marine litter in the deep Mediterranean Sea. Prog. Oceanogr. 118, 273–287.
Schulz, M., Krone, R., Dederer, G., Wätjen, K., Matthies, M., 2015. Comparative analysis of time series of marine litter surveyed on beaches and the seafloor in the southeastern North Sea. Mar. Environ. Res. 106, 61–67.
Shimanaga, M., Yanagi, K., 2016. The Ryukyu Trench may function as a “depocenter” for anthropogenic marine litter. J. Oceanogr. 72, 895–903.
Sudhakar, M., Trishul, A., Doble, M., Suresh Kumar, K., Syed Jahan, S., ... Inbakandan, D., 2007. Biofouling and biodegradation of polyolefins in ocean waters. Polym. Degrad. Stab. 92 (9), 1743–1752. https://doi.org/10.1016/j.polymdegradstab.2007.03.029.
Specifications for oceanographic survey (GB12736-2007). General administration of quality supervision, inspection and quarantine of the People's Republic of China (2007-8-13). Part 6: guidelines for marine ecological survey. http://www.ckjorc.org/cn/admin/news/edit/uploadfile/zhengce/200841719142.pdf.
Spedicato, M., Zupa, W., Carbonara, P., Fiorentino, F., Follesa, M.C., Galgani, F., et al., 2019. Spatial distribution of marine macro-litter on the seafloor in the northern Mediterranean Sea: the MEDITS initiative. Sci. Mar. 83 (S1).
Strafella, P., Fabi, G., Spagnolo, A., Grati, F., Polidori, P., Punzo, E., et al., 2015. Spatial pattern and weight of seabed marine litter in the northern and Central Adriatic Sea. Mar. Pollut. Bull. 91, 120–127.
Tanaka, K., Takada, H., Yamashita, R., Mizukawa, K., Fukuwaka, M.-a., Watanuki, Y., 2013. Accumulation of plastic-derived chemicals in tissues of seabirds ingesting marine plastics. Mar. Pollut. Bull. 69 (1–2), 219–222.
Thurber, A., Sweetman, A., Narayanaswamy, B.E., Jones, D.O.B., Ingels, J., Hansman, R., 2014. Ecosystem function and services provided by the deep sea. Biogeosciences 11 (14), 3941–3963.
Tsai, P., Yeh, H., Chan, T., Chan, B., 2009. Comparison between the catch composition of the French and ORE type beam trawls on deep-sea decapod crustaceans: implications for quantitative sampling of the deep-sea decapod biodiversity. Crustaceana 82 (5), 565–591.
Tubau, X., Canals, M., Lastras, G., Rayo, X., Rivera, J., Amblas, D., 2015. Marine litter on the floor of deep submarine canyons of the northwestern Mediterranean Sea: the role of hydrodynamic processes. Prog. Oceanogr. 134, 379–403.
UNEP, 2015. Biodegradable Plastics and Marine Litter: Misconceptions, concerns and impacts on marine environments. United Nations Environment Programme, Nairobi http://www.unep.org/gpa/documents/publications/BiodegradablePlastics.pdf.
Urban-Malinga, B., Wodzinowski, T., Witalis, B., Zalewski, M., Radtke, K., Grygiel, W., 2018. Marine litter on the seafloor of the southern Baltic. Mar. Pollut. Bull. 127, 612–617.
van den Beld, I.M.J., Guillaumont, B., Menot, L., Bayle, C., Arnaud-Haond, S., Bourillet, J., 2017. Marine litter in submarine canyons of the Bay of Biscay. Deep-Sea Res. II Top. Stud. Oceanogr. 145, 142–152.
Vieira, R.P., Raposo, I.P., Sobral, P., Gonçalves, J.M.S., Bell, K.L.C., Cunha, M.R., et al., 2015. Lost fishing gear and litter at Gorringe Bank (NE Atlantic). J. Sea Res. 100, 91–98.
Watters, D.L., Yoklavich, M.M., Love, M.S., Schroeder, D.M., 2010. Assessing marine debris in deep seafloor habitats off California. Mar. Pollut. Bull. 60, 131–138.
Whiting, S.D., 1998. Types and sources of marine debris in Fog Bay, Northern Australia. Mar. Pollut. Bull. 36, 904e910.
Wilcox, C., Hardesty, B.D., Sharples, R., Griffin, D.A., Lawson, T.J., Gunn, R., 2013. Ghostnet impacts on globally threatened turtles, a spatial risk analysis for northern australia. Conserv. Lett. 6 (4), 247–254. https://doi.org/10.1111/conl.12001.
Woodall, L.C., Robinson, L.F., Rogers, A.D., Narayanaswamy, B.E., Paterson, G.L.J., 2015. Deep-sea litter: a comparison of seamounts, banks and a ridge in the Atlantic and Indian Oceans reveals both environmental and anthropogenic factors impact accumulation and composition. Front. Mar. Sci. 2, 3.
Ye, S., Andrady, A.L., 1991. Fouling of floating plastic debris under biscayne bay exposure conditions. Mar. Pollut. Bull. 22 (12), 608–613.
Zablotski, Y., Kraak, S.B.M., 2019. Marine litter on the Baltic seafloor collected by the international fish-trawl survey. Mar. Pollut. Bull. 141, 448–461.
Zettler, E.R., Mincer, T.J., Amaral-Zettler, L.A., 2013. Life in the “plastisphere”: microbial communities on plastic marine debris. Environ. Sci. Technol. 47 (13), 7137–7146.
Zhang, F., Wang, X., Xu, J., Zhu, L., Peng, G., Xu, P., et al., 2019a. Food-web transfer of microplastics between wild caught fish and crustaceans in East China Sea. Mar. Pollut. Bull. 146, 173–182.
Zhang, C., Zhou, H., Cui, Y., Wang, C., Li, Y., Zhang, D., 2019b. Microplastics in offshore sediment in the Yellow Sea and East China Sea, China. Environ. Pollut. 244, 827–833.