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Plastic contamination in coastal areas around Japan: A review

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Abstract: Publications describing the concentration and distribution of plastic litter, microplastics (> 350 μm and < 5mm), and small microplastics (< 350 μm) in seawater, sediments, and beaches around the coast of Japan are reviewed. Plastics from food packaging and polyethylene plastic bags are widely distributed along the Japanese coast. The concentration of expanded plastics and plastic bottles is high in the region of the East China Sea. Microplastics on the sea surface are widely distributed along the coast of Japan, and the average concentration of microplastics in seawater off the Japanese coast is very high compared with other regions of the world. A two-ply, double neuston net, comprising an internal net with a 350-μm mesh and an outer net with a 50-μm mesh, was used to quantify small microplastics (> 50 μm, < 350 μm) and microplastics (> 350 μm, < 5 mm) in Tokyo Bay. The concentration of small microplastics was about 10 times the concentration of microplastics. Conventional techniques used to quantify microplastics may underestimate plastic concentrations.

Keywords : *microplastic litter, mesoplastics, microplastics, Japan*

1. Introduction

Several million tonnes of mismanaged plastic litter is estimated to be discharged annually from the land into the ocean (LEBRETON *et al.*, 2017; SCHMIDT *et al.*, 2017). Of this plastic material, only 0.27 million tonnes are estimated to be floating on the sea surface (ERIKSEN *et al.*, 2014), with the remainder unaccounted for. The plastic that is not found floating is termed 'missing plastic' (LEBRETON *et al.*, 2019). Many pieces of missing plastic are likely to be sinking to the seabed or drifting in the seawater, but the exact distribution of this material is unknown. However, WEISS *et al.* (2021) assert that the flux of plastic from rivers is overestimated and that there is no missing sink.

Plastic litter at the sea surface is weathered and degraded by UV radiation and/or wave motion (ARTHUR *et al.*, 2009; COLE *et al.*, 2010; GALGANI *et al.*, 2013), gradually breaking into smaller pieces. Plastic fragments that are 5 mm or less in size are referred to as microplastics

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(MPs) (ANDRADY, 2011). Contamination by MPs can have an adverse effect on organisms living in the ocean (GALL and THOMPSON, 2015). Surveys conducted globally have shown that MPs are distributed throughout the ocean and across the globe.

ISOBE *et al.* (2015) reported that the concentration of MPs in East Asian Seas is 1.72 million pieces km^{-2}, 27 times greater than in other oceans around the world. However, the concentration and distribution of plastic litter and MPs in the coastal waters of Japan is poorly understood and needs further investigation.

This review covers the methods used to survey macroplastics and studies that have investigated the concentration and distribution of macroplastic litter of visual size (> several cm), MPs (350 μm to 5 mm), and small MPs (< 350 μm; SMPs) in the coastal area around Japan. In addition, new data on the abundance of SMPs and MPs in Japan coastal waters are also reported.

2. Macroplastic litter

Ghost fishing resulting from lost or dumped fishing gear, has attracted attention in Japan since the 1980s, and research groups have been investigating marine litter in Japanese coastal waters since the 1990s (e.g., KANEHIRO *et al.*, 1996; KURIYAMA *et al.*, 2003; FUJIEDA *et al.*, 2006). The Japan Agency for Marine-Earth Science and Technology (JAMSTEC) created a database of deep-sea images based on visual analysis of submersible video images from 1983–2014. A total of 3,370 pieces of debris were identified from 4,552 surveys in the northwestern Pacific Ocean, of which 1,108 pieces were plastic debris (CHIBA *et al.*, 2018). Research into plastic pollution slowed during the 2000s, but increased again recently as the adverse effects of plastics on marine life is being recognized.

2.1 Methods

Universities and research institutes in Japan started a macroplastic litter survey in 2014, under the leadership of the Ministry of the Environment. A number of training and research vessels from Japanese universities, including the *Kagoshima maru* (Kagoshima University), *Nagasaki maru* (Nagasaki University), *Oshoro maru* (Hokkaido University), and *Shinyo maru* and *Umitaka maru* (Tokyo University of Marine Science and Technology) have participated in the survey, which has been conducted annually since 2014. The location of observation stations used in the 2019 survey are shown in Figure 1.

The survey is conducted by trainees and crews on the training ships, using visual observations. Observers stand on the deck beside the bridge and record information describing the floating objects observed, using a proprietary application software installed on a tablet (Fig. 2). When the observer sights a floating object, an icon is tapped to record the object type, size, distance to the object, number of objects, and color. Floating objects are divided into four categories: artificial objects, fishing gear, natural objects, and unknown. Categories are further divided into subcategories. For artificial objects, subcategories include food packaging plastics, plastic bags, expanded plastics, plastic bottles, glass objects and metal objects. Within the fishing gear category, the subcategories include net (s), buoy (s), and other (s), and for natural objects the subcategories are wood, floating seaweeds, and other (s).

2.2 Concentration and distribution

The results of the 2019 survey were reported by the Ministry of the Environment, Japan, in 2019 (http://www.env.go.jp/water/marine_litter/h31.html accessed on 22 November 2021). The

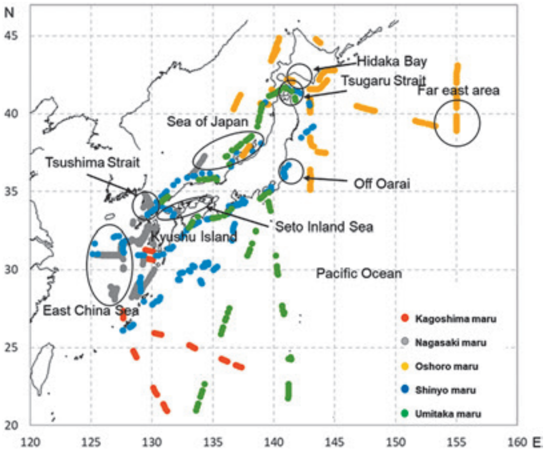

Fig. 1 Location of observation stations used to survey macroplastic litter in 2019. Dots indicate observation points. (Ministry of the Environment of Japan, 2019). The coloured dots represent stations observed by different research vessels.

Fig. 2 Tablet screen showing the interface used to input the floating litter data. (Ministry of the Environment, Japan, 2019)

results from the 2019 report are summarized in Table 1. of the 637 observation stations, food packaging plastics were recorded from 227 stations (36%). The average abundance of food packaging plastic was 2.2 items km^{-2}. The highest density of plastics used in food packaging was 30 items km^{-2}, which was recorded from the Seto Inland Sea. The average abundance of plastic bags was 2.5 items km^{-2}, and the highest density of plastic bags was 167 items km^{-2} reported from an observation point 900 km to the east of northern Japan. Plastic was also abundant in the East China Sea (71.6 items km^{-2}), Tsushima Strait (45–57 items km^{-2}), and to the east of Tsugaru Strait (39.2 items km^{-2}).

The spatial distribution of expanded plastics, polyethylene terephthalate (PET) bottles, and other plastics at the sea surface was similar. The highest abundance of these plastics was recorded from the East China Sea (northwest of Okinawa Island). The average density of expanded plastics was 9.3 items km^{-2}, and the highest density was 116 items km^{-2}. The average density of PET bottles was 1.7 items km^{-2}, and the highest density was 52.4 items km^{-2}. The average density of other plastics (e.g., rope, plastic sheets, buckets) was 21.9 items km^{-2} and the highest density was 304 items km^{-2}.

Expanded plastics, PET bottles, and other plastics were most abundant in the East China Sea, whereas plastic bags and plastics from food packaging, were more abundant offshore from northeastern Japan and in the Seto Inland Sea, respectively (Table 1). Expanded plastics and PET bottles float easily compared with plastic

Table 1. Concentration of macroplastic litter around Japan in 2019.

Plastic type	Detection station ratio (%)	Mean concentration (items km^{-2})	Highest concentration (items km^{-2})	Highest concentration area
Packaging plastics	36	2.2	30.0	Seto Inland Sea
Plastic bags	31	2.5	167	Far east area
Expanded plastics	71	9.3	116	East China Sea
PET bottles	44	1.7	52.4	East China Sea
Other plastics	65	21.9	304	East China Sea

bags, and therefore, the distribution of these plastics is more likely to be affected by ocean currents and winds.

The 2019 report from the Ministry of the Environment also included the results from a bottom trawl survey that examined plastic litter on the seabed. The survey was conducted at three locations, the East China Sea to the west of Kyushu Island, at Hidaka Bay in the south of Hokkaido, and off Oarai to the east of Ibaraki Prefecture (Fig. 1). There were 17 items of marine litter identified from the East China Sea and 37 items from Oarai, of which 47% and 73% were plastics, respectively. However, 3,806 items were recovered from Hidaka Bay, of which 96% were plastics. Hidaka Bay is defined as the area bounded by a line connecting Cape Esan and Cape Erimo (Ohtani, 1981). There is a valley on the adjacent land surrounding the bay which may act as a conduit for plastic waste entering the sea. A peninsula of land extends into Hidaka Bay. The topography of Hidaka may have contributed to the accumulation of marine litter (Kuroda *et al.*, 2020).

3. Microplastics

3.1 Methods

Microplastics (MPs) are defined as plastics from 0.33 to 5 mm in size (e.g., Andrady, 2011). Microplastics were collected using a 350-μm mesh neuston net in Japan (e.g., Isobe *et al.*, 2014; Isobe *et al.*, 2015; Nakano *et al.*, 2021a, b). Microplastics were taken back to the laboratory and Fourier Transform Infrared (hereafter FTIR) spectroscopy was used to identify polymer types. Most researchers pretreat samples (e.g., oxidation treatment or density separation) to remove natural organic matter such as phytoplankton and zooplankton, prior to using FTIR spectroscopy (Nakano *et al.*, 2021a). Pretreatment was not performed in earlier MP studies (e.g. Isobe *et al.*, 2014, 2015).

3.2 Concentration and distribution

According to previous reports (Isobe *et al.*, 2014, 2015), the average density of MPs around Japan (East Asian Seas) was 3.74 pieces m^{-3}, which is 10 times the recorded density of mesoplastics (5–40 mm) at 0.38 pieces m^{-3} (Table 2). The density of MPs in the coastal waters of Japan is 27 times greater than those reported from other oceans around the world (Isobe *et al.*, 2015). The density of MPs in the Seto Inland Sea is 0.4 pieces m^{-3} (Isobe *et al.*, 2014), and the resident population of the adjacent area is about 30 million (https://www.env.go.jp/water/heisa/heisa_net/setouchiNet/seto/g2/g2cat01/index.html). A chemical sample pretreatment (oxidation and density separation) for removing organic matter such as phytoplankton and zooplankton, prior to using FTIR spectroscopy (Nakano *et al.*, 2021a), was not performed in these earlier MP

Table 2. Concentrations of mesoplastics (> 5 mm), microplastics (MPs), and small microplastics (SMPs) around Japan.

Sea area	Classification	Particle size (mm)	Concentration (pieces m^{-3})	Total particle count (pieces m^{-2})	Reference
East Asian Sea	meso	5 <	0.38	—	Isobe *et al.*, 2015
East Asian Sea	micro	0.35 < 5	3.74	1.72	Isobe *et al.*, 2015
Seto Island Sea	micro	0.35 <	0.4	0.4	Isobe *et al.*, 2014
Canal in Tokyo Bay	micro	0.31 << 1	—	2.4–3.2	Matsuguma *et al.*, 2017
Tokyo Bay (Summer)	micro	0.35 << 5	3.98	0.42	Nakano *et al.*, 2021a
Tokyo Bay (Winter)	micro	0.35 << 5	0.55	0.03	Nakano *et al.*, 2021a
Hiroshima Bay	micro	0.3 << 5	—	0.03–0.24	Sagawa *et al.*, 2018
East China Sea	micro	0.35 <<	1.26	—	Nakano *et al.*, 2021b
Offshore Tokai region	small micro	0.05 << 0.35	1060–5901	—	Xu *et al.*, 2022
Tokyo Bay	small micro	0.05 << 0.35	3028–3220	—	Xu *et al.*, 2022

studies (e.g. Isobe *et al.*, 2014, 2015).

This population size is high compared with the resident populations adjacent to the Sea of Japan and the East China Sea, where the concentration of plastic litter was much higher. Modeling suggests that MPs that have accumulated in the Sea of Japan may have originated in the south, before being moved northwards by the Tsushima current (Iwasaki *et al.* 2017). Based on these results, it is difficult to identify the origin of MPs. However, modeling suggests that the MPs found around Japan mainly originate from Japan and its neighboring countries (Iwasaki *et al.*, 2017).

In the report by the Ministry of the Environment of Japan (2019), MPs were categorized into three groups based on shape; described as plastic fragments, expanded plastics, and fibers. There were small amounts of fibers in each size class. The larger-sized expanded plastics (> 5 mm) were present in greater quantities compared with smaller sized pieces (< 5 mm). In contrast, a high proportion of plastic fragments were of a smaller size (< ca. 2 mm). However, it is difficult to collect plastics that are 1 mm or less in size, using a 350-μm mesh neuston net (Isobe *et al.*, 2015; Tokai *et al.*, 2021). Temporal changes in the concentration of MPs during 2014–2019 were also examined in the report. Plastic fragments were the dominant shape identified in the survey each year. The relative concentrations of each of the three plastic groups were stable every year between 2014 and 2019 (Table 3).

Tokyo Bay is an enclosed bay which is subject to a large amount of anthropogenic activity. Samples were collected from five stations in Tokyo Bay in May 2019 and January 2020, using a neuston net (Nakano *et al.*, 2021a) (Table 2). The highest concentration of MPs identified in the study was 17.8 pieces m^{-3} from the center of the bay collected in May 2019. In January 2020, the highest density of MPs recorded was 2.4 pieces m^{-3} from the bay mouth. This result suggests that the concentration of MPs in the bay varies greatly among locations and seasons. This is likely to be related to variation in human activities among locations and seasons. In addition, the movement of plastics in the ocean is greatly affected by currents, which can vary seasonally.

Table 3. The concentration of three major categories of MPs around Japan, 2014–2019.

MPs shape	Concentration (pieces m^{-3})						
	2014	2015	2016	2017	2018	2019	Average
Plastic fragments	3.74	2.38	2.15	0.53	3.71	1.8	2.4
Expanded plastics	1.25	0.28	0.32	0.09	0.46	0.25	0.42
Fibers	0.13	0.06	0.09	0.01	0.05	0.05	0.07

4. Small microplastics

4.1 Methods

To collect small MPs less than 350 μm, a double neuston net consisting of an internal net with a 350-μm mesh and external net with a 50-μm mesh was designed (Fig. 3; Xu *et al.*, 2022). This allows capture of MPs, and small microplastics (SMPs) (50–350 μm) at the same time, from the sea surface.

The double net was used to collect SMPs from Tokyo Bay. The collected samples were subjected to oxidation treatment and density separation, collected on a polytetrafluoroethylene (PTFE) filter, and infrared spectra of the sample were measured using microscopic FTIR (IRT7200, JASCO, Tokyo, Japan). The spectrum was matched against the database KnowItAll (Bio-Rad Laboratories, Inc., Hercules, USA) to identify the type of plastic.

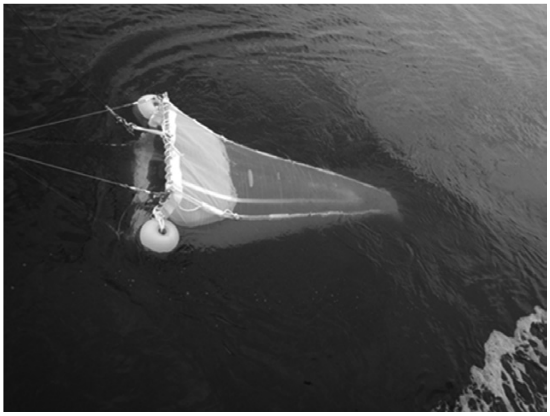

Fig. 3 The double neuston net. The double neuston net has two nets which are set within a single frame. The interior net has a 350-μm mesh and the exterior net has a 50-μm mesh.

4.2 Concentration and distribution

The average concentration of SMPs from Tokyo Bay was 3,028–3,220 pieces m^{-3} (Table 2, Xu *et al.*, 2022). The concentration of larger MPs (> 350 μm) in Tokyo Bay was 3.98 pieces m^{-3} (Nakano *et al.*, 2021a). This indicates that concentration of SMPs in Tokyo Bay could be ca. 1000 times higher than the concentration of MPs. The concentration of SMPs was 1,060–5,901 pieces m^{-3} at the sea surface offshore from the Tokai region (Xu *et al.*, 2022). It is difficult to compare the concentration of SMPs with values from other regions because the methods for sample collection are not standardized. However, the concentration of SMPs is much higher compared with MPs in studies from all regions.

The concentration of SMPs on the seabed was reported for Tokyo Bay (Wang *et al.*, 2021). This study showed that the concentration of SMPs in seabed sediments was higher in the inner part of the bay.

5. Future research needed

A literature search using the 'Web of Science' database (accessed on 12 October 2022) and the keywords "marine", "microplastics", " distribution" and the country name resulted in 399 articles from China, 136 articles from the USA, 80 articles from France and 64 articles from South Korea. In contrast, there were 53 articles from

Japan. This low number of studies on plastic pollution around Japan compared with other nearby countries, highlights the need to increase research effort on this topic.

In most published studies, macroplastics are quantified by visual inspection and video photography, however studies that aim to quantify MPs and SMPs mainly use net sampling. The definition of particle size in each category (e.g., macroplastics, MPs, SMPs) is also inconsistent among studies. It is necessary to develop consistent methodology so that comparisons can be made among studies and study locations.

The units used to describe the concentration (or density) of plastics in seawater also differ due to differences in methods. The density of sea surface microplastics and plastic litters is mainly expressed as "items km^{-2}", whereas the concentrations of MPs in seawater mainly expressed as "pieces m^{-3}", while the concentration of SMPs are mainly expressed as "pieces m^{-3}". Attention must be paid to differences in units when comparing the concentration of plastics among studies.

There are very few independently analyzed studies describing the quantity of mesoplastics (> 5 mm) in oceans. Isobe *et al.* (2015) is the only report on mesoplastics from the waters surrounding Japan. In some studies, mesoplastics have been lumped together with MPs. More rigorous analytical techniques are required to accurately understand the behavior and fate of marine plastic litter.

Surveys of marine debris using resources from the Ministry of the Environment and university training and research vessels allow observations to be made across a wide geographic area. This could be supplemented using volunteers on other vessels to increase the area covered. As the methods used to collect and analyze MPs and SMPs become well established, more results are expected to be reported in the near future. The concentration of MPs in seawater varies greatly among locations and seasons (Nakano *et al.*, 2021a), however more detailed investigation is needed to understand the conditions and mechanisms that influence the concentration and distribution of MPs.

Isobe *et al.* (2014) showed that the MPs collected by a neuston net with a 350-μm mesh reached a maximum value at a particle size of about 1 mm, suggesting that SMPs are not efficiently captured. Tokai *et al.* (2020) also showed that particles with a major axis larger than the mesh opening size were not collected efficiently. The double neuston net captured small particles that went through the 350-μm mesh net. The use of this method will contribute to our knowledge of the behavior and fate of MPs and SMPs.

However, MPs and SMPs are not distributed only on the sea surface. To accurately understand the distribution and behavior of MPs in the marine environment, it is necessary to investigate a range of marine habitats including the coast, the seabed and the water column, and to examine distribution patterns through time.

6. Conclusion

Although there are a few reports describing microplastics in Japan, there are few surveys designed to investigate the quantity and types of plastic litter in the waters around Japan. The distribution of plastic litter differs depending on the type and shape of the plastic. Plastic litter in the waters around Japan is likely to originate not only from Japan but also from other East Asian and Southeast Asian countries. Microplastics are present in high concentrations in seawater along the coast of Japan (average 3.7 pieces m^{-3}). The concentration of small microplastics (SMPs) in seawater is much higher compared with larger microplastics. The concentration and distribution of SMPs requires more detailed investigation.

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