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The current state of marine debris on the seafloor in offshore area around Japan

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ABSTRACT

Marine debris on the seafloor has not been thoroughly investigated, and there is little information compared to other types of marine debris. We conducted bottom trawl surveys to determine the present situation of marine debris on the seafloor in offshore areas around Japan. The survey was conducted in three sea areas with different characteristics. As a result, it was found that the amount of marine debris in submarine canyons (2926.1 items/km^2) was higher than on the continental shelf. It was revealed that most marine debris on the seafloor is comprised of plastic products, and that debris on the seafloor retains its condition for a long time (over 30 years) without deterioration. In addition, the type of marine debris is affected by the industries operating in each area. Continuing to investigate marine debris on the seafloor in more areas will contribute to solving the problem of marine debris.

1. Introduction

In recent years, the problem of marine debris has attracted worldwide attention. Marine debris is also referred to as cross-border litter since it is considered an environmental pollution across international boundaries (Fujieda et al., 2006). In order to solve the problem of marine debris, it is necessary to understand not only the characteristics of inner bays and coastal areas, but also the actual conditions in offshore and open ocean areas.

Marine debris is classified into three groups: marine debris floating on the sea surface; beach debris, which reaches the coast; and marine debris that comes to rest on the seafloor. Among them, marine debris on the seafloor has effects on benthic habitat and the seabed ecosystem, and it decreases operational fishing efficiency because of the added labor to remove debris caught in bottom fishing trawls and damages fish catches (Fujieda et al., 2009). Marine debris on the seafloor is less noticeable than beach debris in daily life, and it is difficult to remove because it is deposited in a special environment of high-water pressure and darkness. In Japan, due to laws and fishery rights, it is difficult to conduct bottom trawl surveys even for research and marine debris collection purposes. For this reason, it is difficult to investigate activities related to the collection of marine debris, to estimate the amount of debris on the seafloor in certain areas (Fujieda et al., 2009; Kuriyama et al., 2003), and to make comparisons with marine debris floating on the sea surface (Galgani et al., 2015). So far, research on marine debris on the seafloor around Japan has been conducted using bottom trawl nets in inner bay areas such as Tokyo Bay (Kanehiro et al., 1995; Kanehiro et al., 1996; Kuriyama et al., 2003), Hakata Bay (Fujieda, 2007), and Kagoshima Bay (Fujieda et al., 2009). Offshore, in the East China Sea west of Kyushu, between 1996 and 2005, Jeonnam University and Pukyong University in South Korea used bottom trawl nets at 39 stations from the south coast of Korea to Jeju Island to investigate marine debris on the seafloor (Lee et al., 2006). In addition, from the offshore area to the open sea, the Japan Agency for Marine-Earth Science and Technology has investigated the distribution of marine debris on the seafloor using images taken by manned submersibles and unmanned, submersible remotely operated vehicles (ROV), and video data taken by an autonomous unmanned underwater vehicle (AUV) (Chiba et al., 2018; Miyake et al., 2011). There are two survey methods for marine debris on the seafloor: submersible surveys and bottom trawl net surveys. When comparing data from different countries and institution, it is desirable to use the same method. However, the bottom trawl survey data for the sea area around Japan is not sufficient.

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Table 1
Area, investigation year, ship name and number of surveys.

Area	Year	Ship Name	Number of surveys	Number of surveys per year	Total number of surveys
Hidaka Bay	2017	Oshoro-maru	1	1	4
	2018	Oshoro-maru	3	3	
Off Joban	2015	Cyuhou-maru	4	8	13
		Ibaraki-maru	3		
		Shinyo-maru III	1		
	2016	Shinyo-maru III	2	2	
	2017	Shinyo-maru IV	1	1	
	2018	Shinyo-maru IV	2	2	
East China Sea	2014	Umitaka-maru	4	9	46
		Shinyo-maru III	5		
	2016	Umitaka-maru	8	8	
	2017	Umitaka-maru	5	20	
		Kagoshima-maru	5		
		Nagasaki-maru III	9		
		Shinyo-maru IV	1		
	2018	Kagoshima-maru	4	8	
		Nagasaki-maru IV	4		
	2019	Shinyo-maru IV	1	1	

In this study, we conducted bottom trawl surveys to determine the present situation of marine debris on the seafloor in offshore areas around Japan. Since it is difficult to cover the entire seabed around Japan with a limited number of research vessels and days, the following survey areas were selected: (1) sea area near the Tsugaru Strait connecting the Japan Sea and the Pacific Ocean (Hidaka Bay); (2) sea area facing the open sea but far from other countries (off Joban); and (3) international sea area that connects waters off Korea, China, and Taiwan (the East China Sea). By comparing the survey results of these three areas, the characteristics of marine debris on the seafloor around Japan were considered.

2. Methods

2.1. Survey areas

The survey was conducted from 2014 to 2018 (Table 1). As described above, the selected survey areas were (1) Hidaka Bay, (2) off Joban, and (3) the East China Sea (Fig. 1). There were four stations in Hidaka Bay, 13 off Joban and 46 in the East China Sea, for a total of 63. The stations in Fig. 1 show the latitude and longitude at the start of each tow (also see Supplementary Table 1).

2.2. Survey period, vessels used and type of net

The surveys of Hidaka Bay was conducted once in October 2017 and three times in September 2018 using the Oshoro-Maru (1598 t), owned by Hokkaido University. The survey off Joban was conducted using the Shinyo-Maru III (649 t) and Shinyo-Maru IV (986 t), owned by the Tokyo University of Marine Science and Technology, the Chuho-Maru (14 t), owned by Kuji-cho Fishery Cooperative, and the Ibaraki Maru (179 t), owned by Ibaraki Prefectural Fisheries Experimental Station. The Shinyo-Maru III conducted one survey in August 2015 and two in August 2016. The Shinyo-Maru IV conducted two surveys in August 2017 and two in August 2018. The Chuho-Maru conducted four surveys in September 2015. The Ibaraki Maru conducted three surveys in November 2015.

The surveys of the East China Sea were conducted using the Umitaka-Maru (1886 t), Shinyo-Maru III (649 t) and Shinyo-Maru IV (986 t), owned by Tokyo University of Marine Science and Technology, the Nagasaki Maru III (842 t) and Nagasaki Maru IV (1131 t), owned by Nagasaki University, and the Kagoshima Maru (935 t), owned by Kagoshima University. The Umitaka-Maru conducted four surveys in October 2014, three in July 2016, five in October 2016, and five in July 2017. The Shinyo-Maru III conducted five surveys in August 2014. The Shinyo-Maru IV conducted one survey in September 2017 and one in February 2018. The Nagasaki Maru III conducted seven surveys in August 2017 and two in September 2017. The Nagasaki Maru IV conducted four surveys in August 2018. The Kagoshima Maru conducted three surveys in October 2017, two in November 2017, two in October 2018, and two in December 2018 (Table 1).

Table 2 shows the bottom trawl net mouth width and mesh size for each ship. The maximum width of the net opening was 30 m for the Umitaka-Maru and the minimum width was 8 m for the Chuho-Maru. The maximum cod end mesh size was 75 mm for the Oshoro-Maru, and the minimum mesh size was with the other ships ranged from 60 mm to 66 mm (excluding 8.3 mm for the Umitaka-Maru). The cod end of the Umitaka-Maru net was split into two, one with a standard mesh size of 60 mm, and the other with a fine mesh size of 8.3 mm. In principle, all bottom trawl nets were towed at a speed of about 2 to 4 knots.

2.3. Sample processing

Marine debris collected from the seafloor by bottom trawl nets was classified by type on board each ship and then cleaned. Any extraneous matter was removed. The debris was then dried in the sun and the length and weight of each item were measured. Classification was based on the marine debris on the seafloor classification of the Ministry of the Environment (Ministry of the Environment Government of Japan, 2016), and included plastic bags, plastic bottles, containers, string, plastic sheets, fishing gear, plastic debris, rubber, Styrofoam, paper, cloth, glass and ceramics, metals, and other artifacts. Other (unknown) items were classified as artifacts. Items such as seaweed, driftwood, terrestrial organisms and sea animal bones were classified as natural objects and were excluded from the analysis. The number of items collected per km^2 was counted to determine the number density.

For measurements, the maximum length and width were measured for sheet-like objects, the length and diameter were measured for string-like objects, and the height and width were measured for three-dimensional objects. The weight of each item was recorded in units of 1 g using an electronic weigh scale or an even balance. The weight of items collected per km^2 was measured to determine the weight density. However, on the Oshoro-Maru, since the number of marine debris items collected was enormous, the length of some of the items was not measured. Each sample was photographed with a digital camera. If there was any information related to the age of the item or the source, such as the date of manufacture, expiration date, or country of origin, it was also recorded.

2.4. Density estimation

In this study, the distance from the time when the bottom trawl net was thrown and the seine net reached the seafloor to the time when the

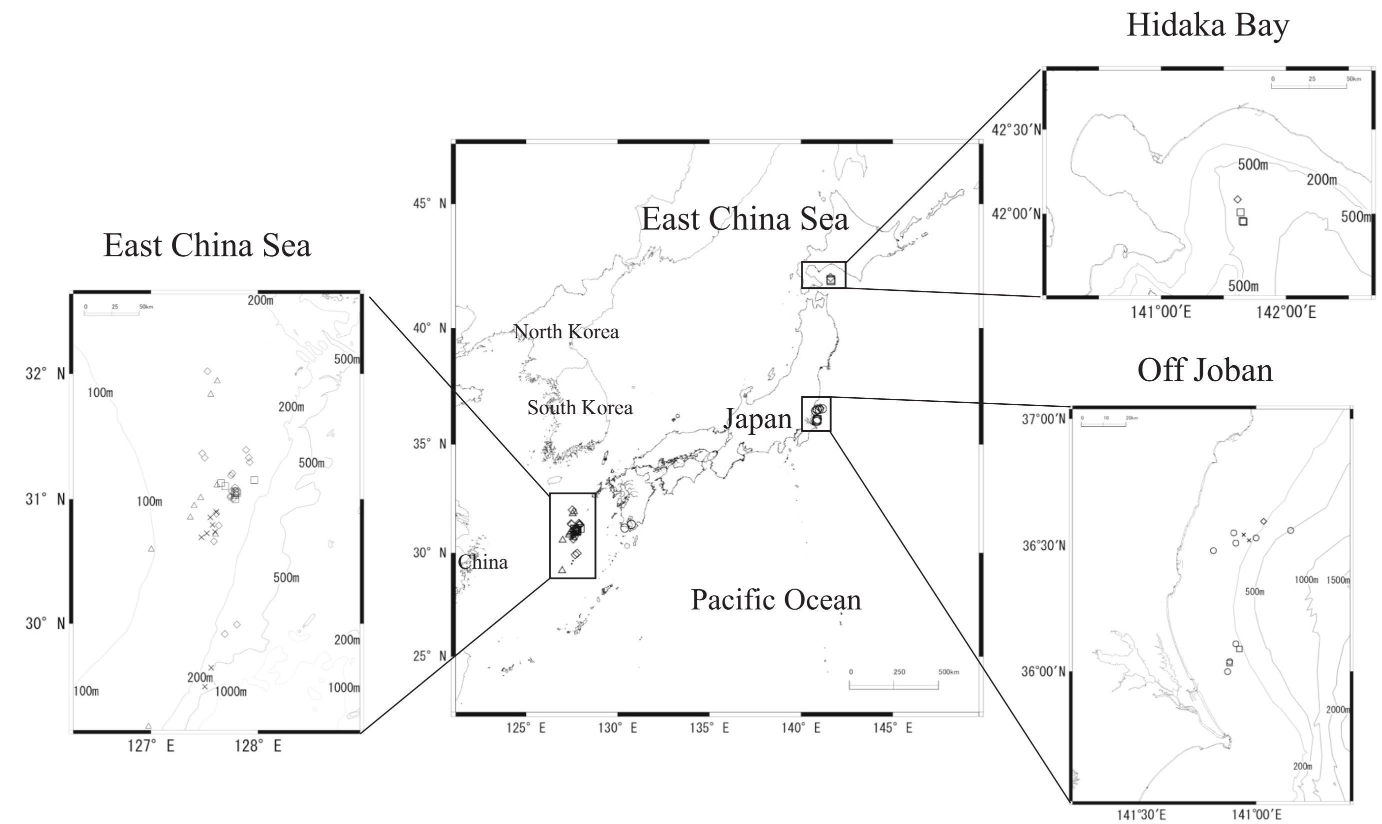

Fig. 1. The location of sampling stations of marine debris on the seafloor. △ 2014, ○ 2015, × 2016, ◇ 2017, □ 2018.

Table 2
Trawl net size of each ship.

Ship Name	Tonnage (t)	Net Mouth Width (m)	Mesh Size (mm)
Umitaka-maru	1,886	30	60/8.3
Shinyo-maru III	649	17	60
Shinyo-maru IV	986	25	61
Nagasaki-maru III	842	17	62
Nagasaki-maru IV	1,131	24	66
Kagoshima-maru	935	23	66
Ibaraki-maru	179	15	60
Oshoro-maru	1,598	25	75
Cyuho-maru	14	8	60

bottom trawl net was hauled back (until leaving the seafloor) was defined as the seine net time, and the seine net distance was calculated from each latitude and longitude as measured by GPS. Then, the minesweeping area was calculated from the width of the opening of the bottom trawl net and the seine net distance, and the marine debris on the seafloor distribution density at each station was estimated by the number and weight per unit area. To determine the significance of differences between sea areas, a Kruskal-Wallis test was performed. The significance level was set at 1% ($\alpha = 0.01$), and the confidence interval was 99%. All statistical analyses were performed on BellCurve for Excel (BellCurve BU, Tokyo, Japan).

3. Results

3.1. Amount of marine debris on the seafloor by area

The total amount and weight of marine debris collected from the seafloor in this survey was 1814 pieces and 75 kg, respectively. The average number density of marine debris collected from the seafloor (± standard deviation [SD]) at the four stations in Hidaka Bay was 2926 items/km^2 (± 698 items/km^2) and the average weight density was 53 kg/km^2 (± 39 kg/km^2). The average number density at the 13 stations off Joban was 326 items/km^2 (± 425 items/km^2) and the average weight density was 29 kg/km^2 (± 39 kg/km^2). The average number density at the 46 stations in the East China Sea was 81 items/km^2 (± 204 items) and the average weight density was 9 kg/km^2 (± 22 kg/km^2). In the East China Sea, there were 11 stations where no marine debris was collected from the seafloor (Supplementary Table 2).

3.2. Production country of the marine debris

Items with labels showing the country where the item was manufactured were compared for each sea area (Fujieda et al., 2009). If the label was in English and no production location information was visible, the country of origin could not be specified, so it was classified as “other”. Marine debris collected from the seafloor with no label information and no country of origin listed was classified as “unknown”. In Hidaka Bay, 23 items were made in Japan, two were made in Korea, and 1271 were unknown. Off Joban, 39 items were made in Japan, one in China, two in Korea, one in other countries, and 125 were unknown. In the East China Sea, seven items were from Japan, 21 from China, five from Taiwan, one from Korea, two from other countries, and 314 were unknown (Table 3).

3.3. Marine debris on the seafloor composition by area

Tables 4-1 and 4-2 show the number density and weight density for each type of marine debris by sea area. Table 4-1 shows that in Hidaka Bay, the number density by type was 1339 items/km^2 for plastic debris (46%), 673 items/km^2 for string (23%) and 420 items/km^2 for plastic sheets (14%). Off Joban, there were 74 items/km^2 for plastic bags (23%), 71 items/km^2 for plastic pieces (22%), and 32 items/km^2 for metals (10%). In the East China Sea, there were 13 items/km^2 for

Table 3
Number of marine debris items collected from the seafloor by country of production in each area.

	Hidaka Bay	Off Joban	East China Sea
Japan	23	39	7
China	0	1	21
Taiwan	0	0	5
Korea	2	2	1
Other	0	1	2
Unknown	1271	125	314

Table 4-1
Number density (items/km^2) of marine debris collected from the seafloor in each area.

Items	Sea area		
	Hidaka Bay	Off Joban	East China Sea
Fishing gear	23.9	12.1	13.4
Plastic sheet	420.5	4.1	0.7
Plastic debris	1339.0	71.1	12.4
Container	14.8	31.2	3.1
String	672.7	30.9	9.9
Bags	138.3	74.2	9.8
Plastic bottle	2.9	1.4	1.7
Styrofoam	0.0	0.0	0.3
Rubber	12.3	6.6	1.8
Paper	5.8	23.6	1.1
Cloth	43.1	17.7	7.7
Glass and Ceramics	21.7	8.0	0.8
Metal	216.4	31.9	7.7
Other	14.5	11.1	10.8
Unknown	0.0	1.8	0.0
Total	2926.1	325.6	81.1

fishing gear (17%), 12 items/km^2 for plastic debris (15%), and 11 items/km^2 for other artifacts (13%). The weight density by type (Table 4-2) showed that in Hidaka Bay, fishing gear was 11 kg/km^2 (21%), string was 9 kg/km^2 (18%), and plastic sheets were 8 kg/km^2 (15%). Off Joban, other artifacts were 9 kg/km^2 (30%), cloth was 7 kg/km^2 (23%), and rubber was 4 kg/km^2 (13%). In the East China Sea, fishing gear was 2 kg/km^2 (26%), other artifacts were 2 kg/km^2 (22%), and metals were 2 kg/km^2 (20%). The fishing gear in Hidaka Bay was comprised of many fishing nets, and the fishing gear in the East China Sea was found to have a lot of nylon fishing line.

Table 4-2
Weight density (kg/km^2) of marine debris collected from the seafloor in each area.

Items	Sea area		
	Hidaka Bay	Off Joban	East China Sea
Fishing gear	10.9	1.0	2.0
Plastic sheet	7.6	0.0	0.3
Plastic debris	7.3	0.9	0.1
Container	0.2	0.2	0.0
String	9.3	2.0	0.6
Bags	6.5	0.4	0.4
Plastic bottle	0.2	0.1	0.1
Styrofoam	0.0	0.0	0.0
Rubber	1.0	3.7	0.3
Paper	0.0	0.2	0.0
Cloth	6.4	6.7	0.4
Glass and Ceramics	0.3	2.0	0.2
Metal	1.8	1.0	1.6
Other	1.2	8.6	1.7
Unknown	0.0	2.2	0.0
Total	52.8	29.1	7.6

3.4. Estimation of accumulation time

Of the 1814 marine debris items collected from the seafloor, 33 items had labels with information such as the date of manufacture or expiration date. Table 5 shows their collection dates, types, and the date information. It is unknown when these items entered the ocean. Therefore, we focused here on the date of manufacture (Sander, 2016; Tramoy et al., 2020). In this study, the date of manufacture was defined as the date of discharge to the ocean (Sander, 2016; Tramoy et al., 2020). In addition, some items had labels with only the expiration date; therefore, the production date of those items was estimated based on the same or similar products. The estimated date of manufacture is shown in parentheses in Table 5. The difference between the manufacturing date and the collection date was defined as the accumulation time in the ocean.

Date information was collected from a total of 33 items, including 14 plastic food packages, 16 beverage cans (eight steel, seven aluminum, one unknown), two cans (food and paint) and one cloth cap (Table 5). The condition of the packaging and labels of 14 plastic products were examined, and 10 were not damaged and two were slightly damaged. The other two were in a state of missing almost half of the original packaging, but since they were clean, there was a possibility that they had already been damaged by the time of runoff. As for the labels, discoloration was observed in 13 out of 14 pieces, but all labels were intact. The items with the longest estimated accumulation time were plastic food packaging of bread, which lasted 34 years (Fig. 2). In addition, food packages with an estimated accumulation time of 30 and 28 years were collected (Table 5). On the other hand, nine items (about 60%) had an accumulation time of less than 2 years (Fig. 3). For metal products, the longest accumulation time was estimated at 12.6 years, followed by 11.3 years. In addition, the accumulation time of about 60% (11 pieces) of plastic products was less than 2 years like plastic (Fig. 3). Furthermore, when focusing on the relationship between collection depth and accumulation time, there was no correlation between depths of 67 m and 830 m, which was range of depths researched in this study (Fig. 4).

4. Discussion

4.1. Accumulation by seafloor topography

Comparing the three sea areas surveyed in this study, the density of items collected in Hidaka Bay was extremely high, and significant differences were found off Joban and in the East China Sea ($p = 0.0236$). Comparing the average density of marine debris collected from the seafloor (excluding natural objects) among the three areas, Hidaka Bay had a number density (2926 pieces/km^2) and weight density (53 kg/km^2) two or three orders of magnitude higher than the other areas. The number density for Hidaka Bay was one of the highest in the world when compared to the Lisbon Canyon, the Guilvinec Canyon, the Setúbal Canyon in the Atlantic Ocean and the Blanes Canyon in the Mediterranean, which were studied by ROV (Pham et al., 2014). In Hidaka Bay, it is known that the Tsushima Warm Current and Oyashio Current merge creating a whirlpool called Tsugaru Gyre. For this reason, it is thought that marine debris is more likely to gather there than in other sea areas. In addition, it is known that submarine canyons tend to accumulate marine debris on the seafloor more easily than continental shelves, continental shelf slopes, and seabed ridges (Pham et al., 2014).

Trawl surveys also show that submarine basins have a higher density of marine debris than submarine valleys and continental slopes. The seafloor topography of Hidaka Bay surveyed in this study was an ocean trough called the Hidaka Trough (Noda et al., 2013). This suggests that Hidaka Bay is more likely to accumulate marine debris on the seafloor than the area off Joban, a slope-shaped terrain that gradually becomes deeper from land to offshore, and the East China Sea area, which was on the continental shelf and the margins of the continental

Table 5
Date of production and expiration of marine debris collected from the seafloor in each area.

Date	Station No.	Sea area	Item category	Production date	Expiration date	Production Country
2014.10.08	9	East China Sea	Steel can	2013.05.22		China
			Aluminum can	2014.3.7		China
2015.09.15	2	Off Joban	Food packaging	1981.06.09		Japan
			Steel can	2014.06.23		Japan
2015.09.15	3	Off Joban	Food packaging	(2014.01.10)*	2014.01.15	Japan
			Food container	(2015.5.30)*	2015.06.12	Japan
			Food container	2013.10.18	2014.08.13	Japan
			Aluminum can	(2015.04)*	2016.04	Japan
			Steel can	(2014.09)*	2015.09	Japan
			Steel can	2013.08.18		Japan
			Food can	(2013.11.25)*	2016.11.25	Japan
			Aluminum can	2013.8		Japan
			Steel can	2015.7.23		Japan
			Steel can	2014.1		Japan
2015.09.15	5	Off Joban	Food packaging	(2015.4.12)*	2017.04.12	Japan
			Food packaging	(2015.9.24)*	2016.03.24	Japan
			Steel can	(2014.4.30)*	2015.04.30	Japan
			Aluminum can	2012.3.12	2013.08	Japan
2016.07.18	2	East China Sea	Steel can	2015.6.17		China
			Aluminum can	2015.7.5		China
2016.07.18	3	East China Sea	Food packaging	(2015.7.9)*	2016.1.9	China
			Food packaging	(2014.8.10)*	2014.12.10	China
2016.08.06	5	Off Joban	Food packaging	(2015.2.9)*	2016.02.09	Japan
2016.10.08	7	East China Sea	Aluminum can	(2012.8.26)*	2013.08.26	Japan
2016.10.10	9	East China Sea	Cloth Cap	2001		China
			Aluminum can	2004.3.16		Taiwan
2017.07.19	4	East China Sea	can	(2014.11.1)*	2015.11.1	Japan
2017.10.18	20	Hidaka Bay	Sheet plastic	2015.3.3		Korea
2017.11.26	21	East China Sea	Aluminum can	05.05.18	2006.08.17	Japan
			Food can	(2017.5.2)*	2020.5.2	Japan
2018.09.26	8	Hidaka Bay	Food packaging	1988.9.23		Japan
			Sheet plastic	2008.11.1		Japan
2018.09.29	9	Hidaka Bay	Food packaging	1988.11-1990.5		Japan

* Production date was estimated based on the same or similar products.

shelf. On the other hand, there were 11 stations on the continental shelf in the East China Sea where no marine debris was collected from the seafloor. In addition, bottom trawl surveys conducted by a Korean training ship in the East China Sea showed that there were also stations where no debris was collected (Lee et al., 2006). This supports the theory that marine debris is unlikely to accumulate on the seafloor in flat areas such as on a continental shelf.

4.2. Marine debris on the seafloor composition

Next, the composition of marine debris on the seafloor was considered based on the number density. Despite the difference in the percentage of total marine debris, plastic products (sheets, debris, containers, string, bags, plastic bottles, Styrofoam) accounted for the largest proportion in all sea areas (Hidaka: 89%, off Joban: 69%, East China Sea: 34%). The tendency for plastic products to account for the highest proportion has been confirmed in other surveys conducted in Japan's inner bays [Tokyo Bay (47–75%: Kanehiro et al., 1995; 40%: Kanehiro et al., 1996; 36%: Kuriyama et al., 2003), Hakata Bay (22.2%: Fujieda, 2007), Kagoshima Bay (49%: Fujieda et al., 2009)] and in Europe [Adriatic Sea (80%: Pasquini et al., 2016), the northeastern Mediterranean (73%: Eryaşar et al., 2014), the eastern Mediterranean (59–95%: Ioakeimidis et al., 2014), and the Black Sea (45%: Ioakeimidis et al., 2014)], confirming again that plastic products are a dominant type of marine debris in many sea areas.

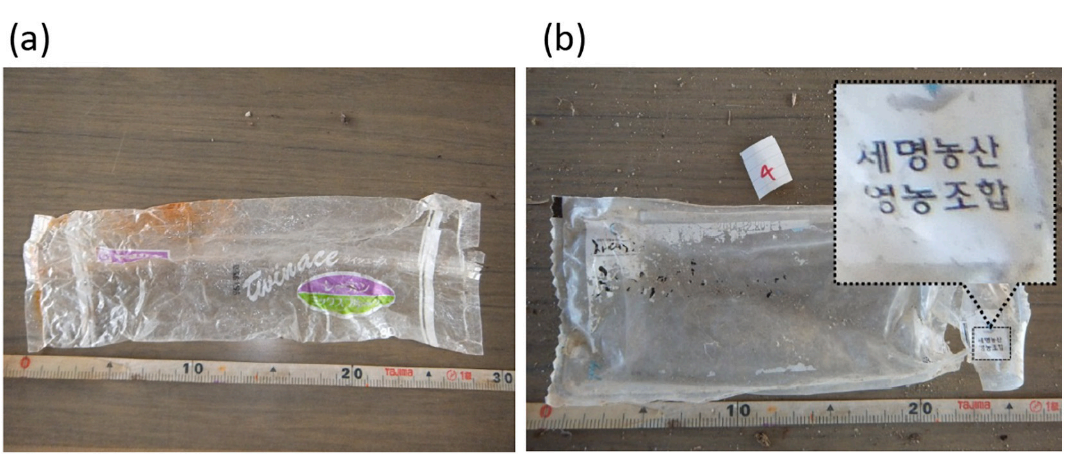

Fig. 2. Plastic food packages collected as marine debris on the seafloor. (a) Plastic food packaging collected at a depth of 67 m off Joban with an estimated accumulation time of 34 years and 3 months. (b) Plastic food package made in Korea collected at a depth of 100 m off Joban.

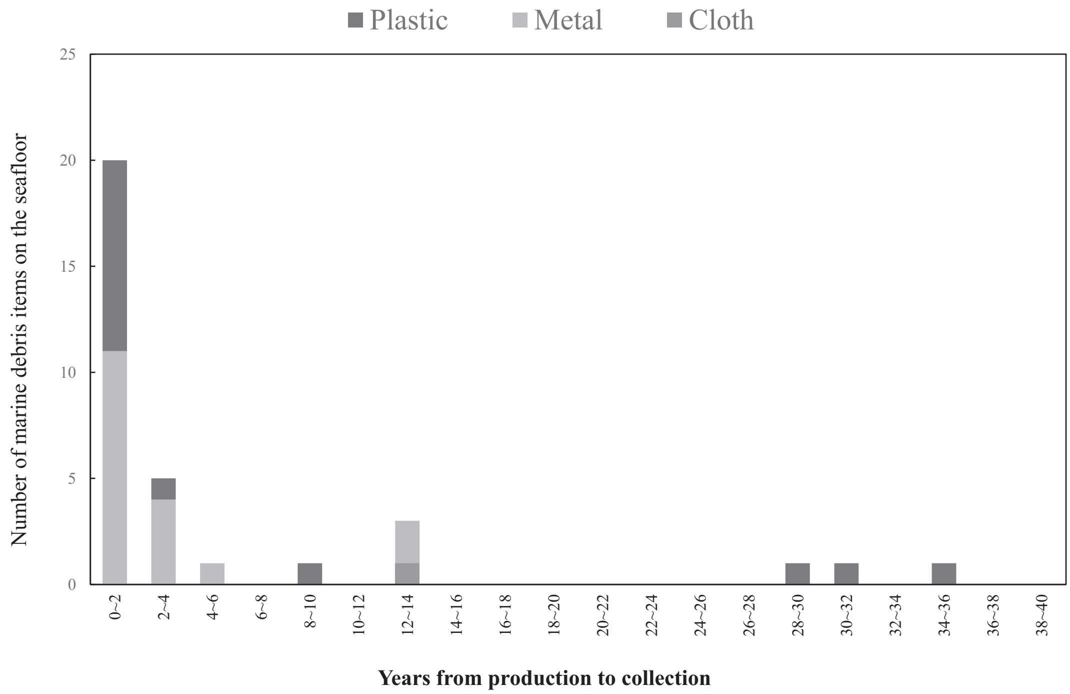

Fig. 3. Estimated accumulation time and number of collected plastic and metal items.

4.3. Country of origin

In order to estimate the source of the marine debris collected from the seafloor in this study, the country of origin and accumulation time were investigated. However, it is unknown when and where the collected marine debris ran into the ocean. Therefore, we focused on the difference in the number of overseas products discovered in the study areas.

The largest collection of foreign-made marine debris was collected from in the East China Sea. For the 34 items whose country of manufacture was confirmed, seven were from Japan, 21 were from China, five were from Taiwan, and one was from Korea. This suggests products produced by countries facing the East China Sea were collected in that area. Off Joban, 39 out of 42 items were from Japan, one was from China, two were from South Korea, and in Hidaka Bay, 23 out of 25 items were from Japan and two were from Korea. The farther away from the East China Sea, the less foreign-made marine debris was collected from the seafloor. The foreign-made marine debris collected from the seafloor in Hidaka Bay and off Joban in this study consisted only of plastic products such as food packaging (Fig. 2), and the metal cans that were collected (one in Hidaka Bay, nine off Joban) were all made in Japan. Meanwhile, in the East China Sea, four out of eight metal cans collected were made in Japan and four were made in China.

It is known from past research on beach debris that foreign-made marine debris arrives on the coast of Japan (Fujieda et al., 2009). The results suggest that plastic packaging with a low specific gravity takes

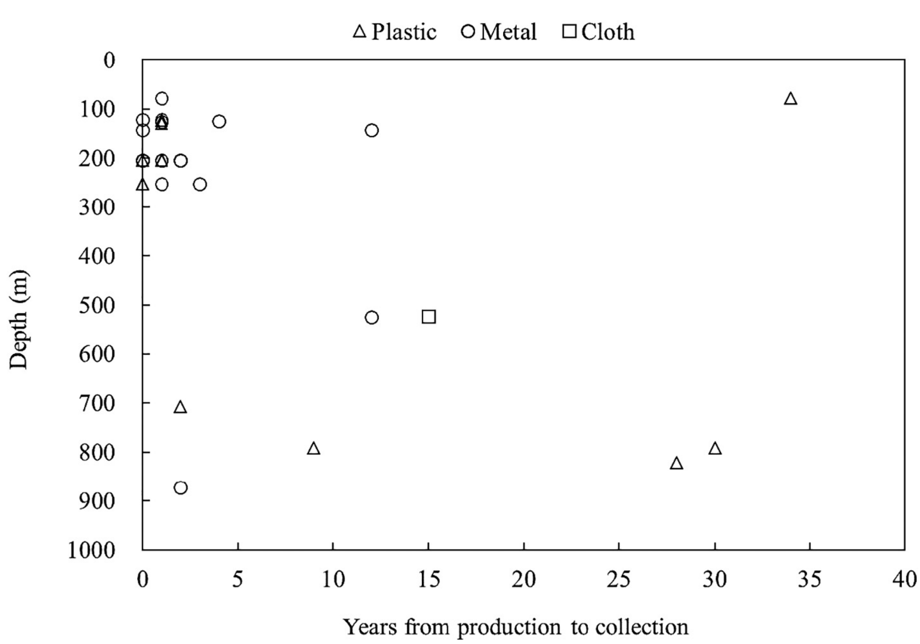

Fig. 4. Relationship between estimated accumulation time of collected plastics, metals, and cloths and collection depth.

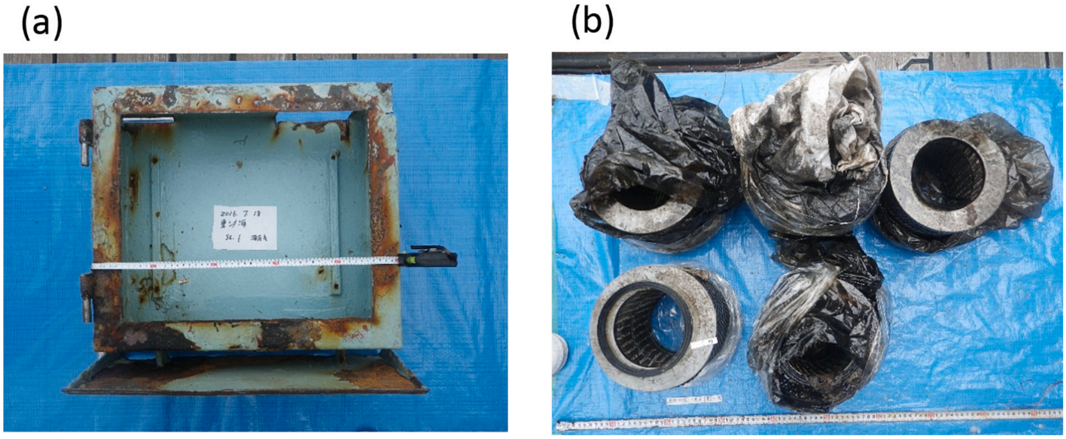

Fig. 5. Switchboard (a) and fuel strainer (b) collected in the East China Sea.

time to sink, so it tends to drift with the ocean currents, and metal products with a high specific gravity tend to stay near the runoff source.

4.4. Accumulation time

Some of the text printed on the labels of marine debris collected from the seafloor confirmed not only the country of origin, but also when it was produced. It is known that ultraviolet rays that are capable of degrading plastics do not always reach the seafloor, the water temperature is low and stable, and oxygen is also low, so deterioration does not occur (Andrady, 2015). By estimating the date of manufacture in the present study, it was found that plastic food packaging that had settled on the seafloor kept its shape without deterioration for more than 30 years. From this, it was confirmed that the plastic products that settled on the seafloor continued to remain on the seafloor without deteriorating, keeping their original shapes. The results of this survey showed that such phenomena occur even on the seafloor at depths of about 67 m.

On the other hand, for metal products, the longest estimated accumulation time in this survey was 12 years, less than half that of plastic products. Metals corrode more quickly than plastics, and surveys from Tokyo Bay have shown that 50% to 60% have been lost in 1 year (Kuriyama et al., 2003). Thus, it was thought that metal products deteriorate in the sea faster than plastic products. In the future, it may be necessary to conduct surveys such as placing a sample on the seafloor and following the progression of corrosion.

4.5. Outflow cause

Focusing on the results from Hidaka Bay, the plastic products collected were mostly plastic sheets or plastic debris, which were originally considered to have no printed labels, and were tens to hundreds of times more numerous than plastic products collected in the other two sea areas. One source of plastic products in Hidaka Bay was agricultural plastic sheets used in greenhouses or as mulch. The reason for this is that Hokkaido, which faces Hidaka Bay, is one of Japan's leading agricultural areas, and accounts for the highest amount (20%) of plastic sheets used for agriculture in Japan (Ministry of Agriculture, Forestry and Fisheries Government of Japan, 2001). 90% of plastic sheets are reused, recycled, incinerated or landfilled. On the other hand, in recent years, there have been many natural disasters such as typhoons that hit the Hokkaido region, and it is possible that plastic sheets used in fields and by farmers may have washed away into the sea during disasters. In the future, it is necessary to clarify the source of plastics through detailed analysis of materials and to consider countermeasures to prevent the release of such marine debris into the ocean.

In the East China Sea, fishing gear accounted for a higher percentage of artificial objects than off Joban or in Hidaka Bay. Fishing gear accounted for 17% of the total density and 26% of the weight density in the East China Sea. Surveys conducted on a training ship from Jeonnam University in Korea reported that 42 to 72% of the marine debris collected from the seafloor in the East China Sea was fishing gear (Lee et al., 2006). The East China Sea has a continental shelf with a depth of less than 100 m and fishing is actively conducted by Japan, China, and Korea. In the East China Sea, where the stations were far from land, the amount of marine debris collected from the seafloor that was considered to be land-based litter was smaller than that in the other two sea areas. Most of the fishing gear collected in Hidaka Bay was fishing nets, while most were nylon fishing line in the East China Sea. Hidaka Bay uses fishing nets such as gill net fishing and bottom trawl net fishing (https://www.hro.or.jp/list/fisheries/marine/index.html). On the other hand, in the East China Sea, since the Horsehead tilefish longline fishery and the puffer fish longline fishery are carried out in the East China Sea (Tokimura, 2011), it was thought that this was runoff from the longline fishery. From this fact, it is possible that fishing gear that becomes marine debris on the seafloor is largely related to the fishing method used in the sea area. Apart from fishing gear, there were also two marine debris items that were thought to have been dumped from ships based on their shape and type (Fig. 5). The first item was an iron box collected from the East China Sea on July 18, 2016, presumed to contain electronic control boards and the like, weighing 2100 g. The second was five fuel strainers (440 g each) collected from the East China Sea on October 10, 2016. Although some metal products like cans are light enough to drift, these two types of metal debris were considered to have been dumped into the ocean because of their weight and structure. On the seafloor of offshore areas such as the East China Sea, more than 100 km away from land, it was thought that the amount of ghost fishing gear and illegal dumping from ships passing through the area were higher than in other areas. Marine debris collected from the seafloor in surveys conducted in the Adriatic Sea have also reported that the amount of debris from cage nets used for mussels decreases with distance from the farms (Pasquini et al., 2016). In this way, most of the marine debris collected from the seafloor was considered to be closely related to the surrounding areas connected to the sea and the industries that use the nearby sea area.

5. Conclusion

In this study, we compared the results of surveys in three different sea areas to clarify the current state of marine debris on the seafloor in the sea area around Japan. As mentioned in the Introduction section, there is concern about the impact that marine debris on the seafloor has on fisheries. In recent years, it has been suggested that marine debris on the seafloor may also affect the size selectivity of fish catches (Eryaşar et al., 2014). Marine debris can block small fish from escaping the mesh of bottom trawl nets, leading to increased bycatch. This is thought to lead to a decrease in fishery resources. It has also been said that marine debris on the sea can provide shelter for living organisms and offer sites for spawning, which can lead to the development of unusual ecosystems (Katsanevakis et al., 2007). Since marine debris on the seafloor can affect not only human activities but also the entire ocean ecosystem, it is an urgent problem to be solved.

The results of this study suggest three things. First, the topography of the area affects the accumulation of marine debris on the seafloor. Second, most marine debris on the seafloor is plastic products and tends to maintain its shape for a long time without deterioration. Third, the source of marine debris on the seafloor is related to the surrounding area and the ships that use that sea area. If the conditions that lead to the accumulation of marine debris on the seafloor are clarified, it will be easier to develop methods of efficiently removing it. Furthermore, if probable sources are identified, it will be possible to consider countermeasures specific to each region and industry, and to take measures to prevent runoff into the ocean. In this regard, it is important to continue to survey marine debris on the seafloor in more areas. On the other hand, it is known that bottom trawl nets have varying levels of collection efficiency because the structure and mesh size differ depending on the ship (Lewy et al., 2004).

In addition, there are two types of surveys of marine debris on the seafloor: one using a bottom trawl net, as in this study, and one using a ROV or submarine (Miyake et al., 2011; Chiba et al., 2018). It is possible that the quality of the data obtained differs depending on the equipment used. In order to understand the actual situation of marine debris on the seafloor more accurately in the future, and to compare different survey methods on the same scale, it is necessary to conduct surveys of the same sea area using different equipment.

CRediT authorship contribution statement

Mao Kuroda: Conceptualization, Formal analysis, Investigation, Writing - original draft, Visualization, Funding acquisition. **Keiichi Uchida:** Investigation, Writing - review & editing, Supervision, Project administration, Funding acquisition. **Tadashi Tokai:** Funding acquisition, Writing - review & editing. **Yoshinori Miyamoto:** Writing - review & editing. **Tohru Mukai:** Investigation, Resources, Writing - review & editing. **Keiri Imai:** Investigation, Resources, Writing - review & editing. **Kenichi Shimizu:** Investigation, Resources, Writing - review & editing. **Mitsuharu Yagi:** Investigation, Resources, Writing - review & editing. **Yuichi Yamanaka:** Investigation, Resources, Writing - review & editing. **Takahisa Mituhashi:** Investigation, Resources, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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