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Current Situation for Research into the Marine Issue of Microplastics, and Future Challenges

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1. Introduction

The issue of marine plastics covers a wide range of problems, including the impact on the marine environment, obstruction to the navigation of vessels, impact on the living environment in coastal regions, and damage to the tourism and fishery industries. Furthermore, as microplastics[1] adsorb toxic chemical substances in the ocean, such as polychlorinated biphenyl (PCB), there are concerns that they may have a serious impact on marine organisms, marine ecosystems, and further, on human health, through the food chain.[2,3]

According to a report by the World Economic Forum in 2016, the total weight of marine plastics is expected to exceed the total weight of fish by 2050.[4] In 2018, United European Gastroenterology (UEG) announced that microplastics are already being absorbed into the human body.[5] A study conducted jointly by a research group from the Republic of Korea and the environmental protection organization, Greenpeace East Asia, established that 90% of the table salt in the world contains microplastics.[6] Marine pollution by plastics has been observed even at the North and South Poles, as well as on the deep seabed, and is becoming a serious global issue.[7,8,9]

Understanding the actual situation of plastics in the oceans is a key point to resolving this issue. This study reviews the monitoring methods and observation platforms for microplastics in Japan, and considers future challenges related to microplastics as well as paths for resolving them.

[1] A micro-sized fragment of plastic that is less than 5mm in length.

2. Current situation for monitoring methods on marine microplastics

The method for monitoring the actual situation of microplastics is divided into two steps—collection of microplastics samples and quantitative analysis in the laboratory. (Figure 1)

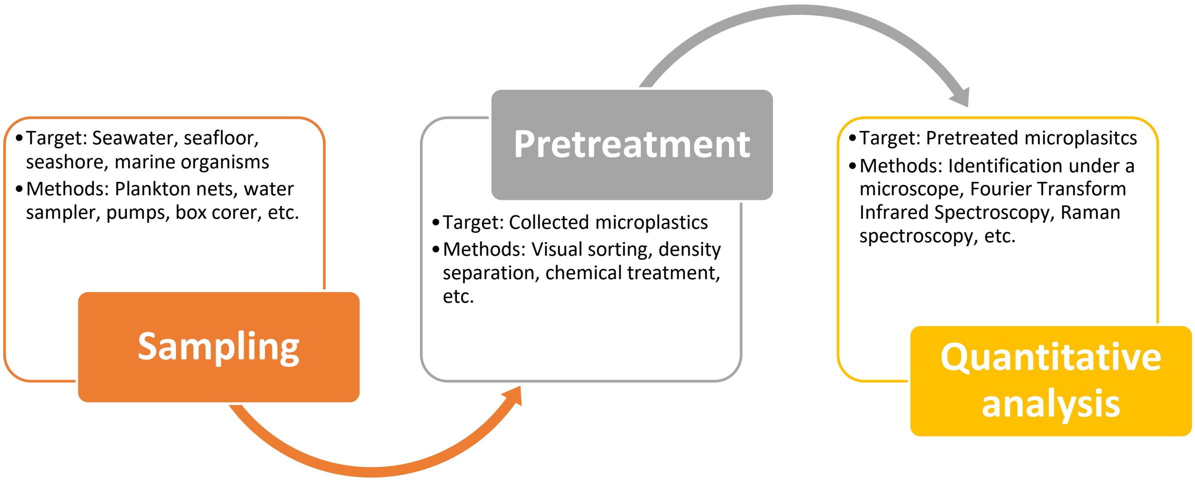

Figure 1 Procedures for monitoring method of marine microplastics

2.1 Collection of microplastics

Microplastic samples are mainly collected from seawater, the seafloor, seashores, and marine organisms. Different sensors (methods) are used for each type of target.

By analyzing samples obtained from seawater, it is possible to learn about the current situation for microplastics on the surface of the sea or the target water depth. The subject of current research is often microplastics floating on the surface of the sea, at a depth of about 0 to 0.5 m. To collect samples from the surface of the sea, the Neuston net and Manta net, which are types of plankton nets, are frequently used.[10,11,12] The mesh size of these nets range from 100 to 500 µm. Mesh sizes that are finer than this would enable the collection of even smaller microplastics, but as they are easily clogged up in the water, nets of about 330 µm are frequently used.[11,12] This gives rise to the problem of underestimating the quantity of microplastics on the surface of the sea, as microplastics that are smaller than 330 µm cannot be picked up by these nets.

When undertaking a study on microplastics at the target water depth, a water sampler such as a Niskin bottle is used. When studying the vertical distribution of microplastics, a multiple opening and closing plankton net is used.[11,12] To collect microplastics at the surface of the sea (up to about 10 m deep), pumps and continuous plankton recorders (CPR) are often used. Seawater samples obtained through pumps offer the advantage of being able to collect microplastics by size at the same time, by passing the water samples through multiple filters with different mesh sizes. However, the volume of water that can be filtered per hour is smaller in comparison with collections using nets.[11]

The collection of sediments using devices known as corers (box corer, push corer, or multiple corer) that are operated through human occupied vehicles (HOV) or remotely operated vehicles (ROV), makes it possible to analyze the actual situation of microplastics that have sunk onto the seafloor.[11,13,14] However, as the calculation methods for the density of microplastics in sediments, as well as the depth for collecting samples, vary across each study, it is probably difficult to compare the results from the various studies and research.

Research on the quantity of microplastics drifting along the seashore is an effective method for understanding the distribution of microplastics in the sea and in bays. Generally, a square sampling area is established at the beach where the study is to be conducted, the sand on the surface is scooped up and sifted by a sieve to extract the sand samples. Microplastics contained in the samples are then examined.[11,15]

It is also possible to use marine organisms as the target sample, and study the quantity of microplastics accidentally ingested by these organisms. The organisms collected are dissected, then the quantity and weight of microplastics in their digestive tracts measured, in order to gain a better understanding of the marine microplastics situation.[11,14,16]

2.2 Quantitative analysis of microplastics

It is necessary to carry out pretreatment in order to quantify the microplastics collected from the sea, such as identification of sizes and shapes, determination of materials, etc.; in other words, it is necessary to separate the plastics from the non-plastics first. The easiest separation method is to sift and filter the samples, and pick out the microplastics through a visual sorting process.[11,12] This method enables the efficient removal of large living organisms, seaweed, and other irrelevant items, but requires a huge amount of time, as sorting is carried out visually. For this reason, other methods are also widely used, such as density separation and chemical treatment. Density separation is a method that makes use of the density difference between plastics and non-plastics (for example, sediments, sand, etc.) to separate out the microplastics, using a saline solution such as sodium chloride ($NaCl$).[11,12,17] Many inorganic substances can be removed through density separation, but organic substances (such as plankton, detritus, etc.) can be removed more effectively through chemical treatment. In particular, processing methods such as the breaking down of organic substances using acidic and alkaline chemical reagents (such as nitric acid, sodium hydroxide, etc.), and organic substance oxidation using hydrogen peroxide, are widely used.[18,19] Separation can be carried out more efficiently by using a combination of several processing methods.

Using the pretreated samples, quantitative analysis is carried out by identifying the sizes and shapes of the microplastics, and determining their materials. Microplastics of several hundred µm and larger can be directly sorted with the naked eye, but smaller fragments have to be enlarged using a stereoscopic microscope or a high-resolution electron microscope in order to sort the microplastics out. The shapes, sizes, and quantity of microplastics are determined through digital image processing.[11,12,20] The materials of the microplastics (polyethylene (PE), polypropylene (PP), etc.) are then determined through spectroscopic analysis. Usually, Fourier Transform Infrared Spectroscopy (FTIR) or Raman spectroscopy, which can carry out highly reliable identification of the polymers, are used.[12,20]

However, current quantification methods for microplastics rely mainly on manual work, which takes time, is inefficient, and lacks analytical accuracy, as operations are carried out by hand. The Japan Agency for Marine-Earth Science and Technology (JAMSTEC) has commenced research on high-speed detection and classification methods, and developed a new method for studying microplastics in 2020.[21] Specifically, by focusing on the fact that each type of plastic material has unique spectral reflection characteristics, it has succeeded in using hyperspectral imaging (HIS) technology and gold-coated polycarbonate filters with high filtration performance, to detect fine microplastic particles down to 100 µm in diameter and identify their materials. In terms of time, it takes about 10 seconds to scan a filter surface of 1cm × 1cm; compared to the conventional FTIR method, it has been confirmed that this method is able to evaluate microplastics about 100 times faster. Going forward, there are plans to apply the method to actual samples in seawater, and to develop a high-speed, automatic measuring system that is combined with a flow system to collect microplastics in water.[21]

Furthermore, the Draper Laboratory in the United States, jointly with the United States Environmental Protection Agency (EPA), has plans to develop the world's first Microplastics-Sensing Autonomous Underwater Vehicle (AUV), equipped with a sensor that can measure the quantity, sizes, and materials of microplastics in seawater in real-time.[22]

3. Current situation of marine microplastics observation platforms

In Japan, the main organizations conducting observational studies on microplastics include the Ministry of the Environment, universities, research institutions, regional research institutions, local governments, and private corporations. These organizations use a wide variety of research methods and sampling equipment. This section classifies these organizations, which are here regarded as observation platforms.

3.1 Ministry of the Environment

Since 2014, the Ministry of the Environment, in cooperation with Kyushu University and Tokyo University of Marine Science and Technology, has been conducting research on the distribution status of microplastics in 69 locations off the coasts of Honshu, Shikoku, and Kyushu. Moreover, since 2017, it has continued the research while expanding the scope to 109 locations, including sea areas in southern Japan, while also expanding the collaborative structure with universities to include Hokkaido University, Nagasaki University, and Kagoshima University, in addition to the aforementioned two universities. In the research, observation ships (Umitaka Maru and Shinyo Maru, belonging to the Tokyo University of Marine Science and Technology) trawled Neuston nets with an opening measuring 75 cm×75 cm, 30 cm in length, and mesh size of 350 μm, for 20 minutes at a speed of 2 to 3 knots, to collect microplastics. Quantitative analysis of the samples showed that microplastics are distributed across the whole of the offshore sea areas around Japan, with a large quantity observed in the northern part of the Sea of Japan, offshore of Tohoku from Hokuriku, while a high density was also observed off the western part of Sanin, along the Pacific coast of Kyushu and Shikoku, and offshore of Sanriku from the Tsugaru Channel.

In addition to studies on the ocean, since 2018 the Ministry of the Environment has also conducted fact-finding research on microplastics in rivers, which is a possible cause of marine waste. Surveys, including trial collection of samples, were conducted at the Tamagawa River and Tsurumigawa River. Going forward, there are plans to establish methods for monitoring microplastics in rivers, conduct fact-finding studies, and estimate the quantity of microplastics flowing from rivers into the oceans, etc.

3.2 Universities

With assistance from the Environment Research and Technology Development Fund disbursed by the Ministry of the Environment, a research group from Kyushu University, led by Professor Atsuhiko Isobe, used Tokyo University of Marine Science and Technology's Umitaka Maru in 2016 to conduct transoceanic surveys, meridionally, from Antarctica to Japan. This study shed light on the distribution of marine microplastics in the upper ocean.[23] Microplastics were collected using a Neuston net with an opening measuring 75 cm×75 cm, 30 cm in length, and mesh size of 300 μm, trawled from the Umitaka Maru for 40 minutes at a speed of 2 to 3 knots. The collected samples were then measured at Kyushu University. Then, four numerical models were used (Figure 2) to reproduce the abundance of pelagic microplastics measuring 300 μm and larger observed in the meridional survey in 2016, and to predict the future abundance of pelagic microplastics over the Pacific Ocean up to 50 years. The result of this study suggested that, if the amount of plastic waste flowing into the oceans keeps on increasing at the current rate, the weight concentration of pelagic microplastics in the upper ocean would increase twofold by 2030 (compared to 2016) and fourfold by 2060, posing greater risk to the environment.[23]

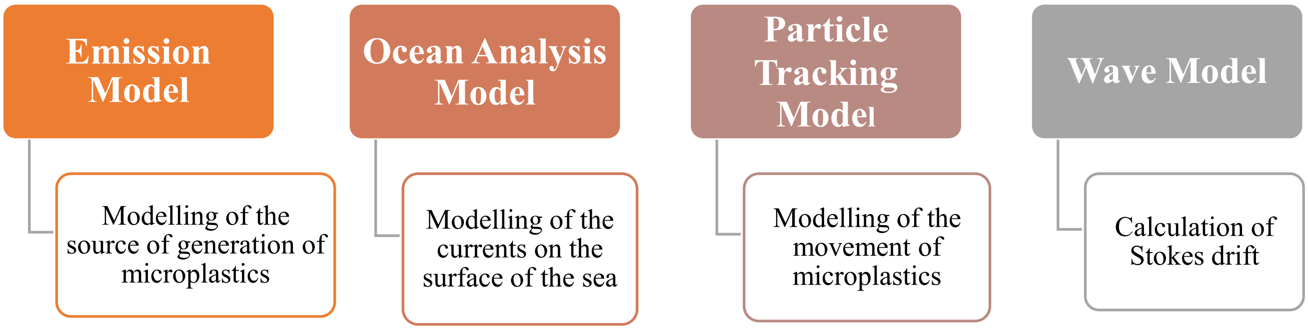

Figure 2 Numerical models to simulate the abundance of microplastics (Prepared by Isobe, A et al., 2019)

A research group led by Professor Yasuo Nihei of Tokyo University of Science conducted a study from 2015 to 2017 on the actual situation of microplastics in river water, at 26 points in 23 rivers. They used simplified plankton nets (aperture 30 cm, length 75 cm, and mesh size 350 μm) to collect microplastics in the rivers from a bridge over a period of 10 to 30 minutes. As a result, microplastics were discovered at all observation points in all the rivers. The highest level was observed at Shirakawa River in Kumamoto Prefecture.[24,25]

3.3. Research institutes

In 2019, JAMSTEC conducted a study on the distribution of microplastics at 15 selected survey points in the “Western Pacific Garbage Patch” off the southeastern coast of Japan, or, in short, the wide sea area extending from Chichijima of the Ogasawara Islands to Sagami Bay, deemed one of the places where marine plastics tend to accumulate (https://www.jamstec.go.jp/shinkai6500/reports/yk19-11.html Cruise Report R/V Yokosuka & Shinkai 6500 YK19-11). Microplastics on the surface of the sea were collected using Neuston nets of mesh size 300 μm, while the research voyage was carried out by the research vessel Yokosuka. A study was also conducted on marine plastics that had sunk into the deep sea. A manned research submersible, “Shinkai 6500” was used to reach depths of up to 6,500 m under the sea a total of six times, from Sagami Bay to offshore of the Boso Peninsula, collecting waste from the seafloor as well as mud and water samples. Furthermore, in order to study the impact of microplastics on living organisms, samples of benthonic organisms such as sea cucumbers were also collected. For deeper waters (6,500 m – 9,200 m), the Free Fall Camera System developed by JAMSTEC was used twice to collect water, mud, and living organism samples, as well as take camera images.

Apart from this study, JAMSTEC also collaborated with private-sector institutions on the study of microplastics. In the Japan-Palau Goodwill Yacht Race held from December 2019 to January 2020, the racing yacht TREKKEE and race escort ship MIRAIE were equipped with samplers to collect microplastics through continuous observation along the navigation route in the western North Pacific linking Japan and Palau.[26] During the period of the study, microplastics were collected using two methods. The first method used a sampler that could collect microplastics from the surface of the sea semi-automatically, collecting microplastics smaller than 300 μm across a range of 3,000 km. Microplastics were collected by the semi-automatic samplers fitted with three metal filters (mesh size: 30, 100, 300μm). In the second method, a Neuston net with mesh size of 335 μm was used and trawled for 30 minutes at a speed of about 2 knots, to collect microplastics from the surface of the sea. Initial results showed that microplastics were distributed across a wide area of the sea areas surveyed. Moreover, the density of the microplastics was highest at the observation points off Sagami Bay on the coast of Japan, while density was lowest at the observation points along the coast of Palau. The success of this project opened up the possibility for further collaboration between marine scientists and the private sector in the future.[26]

Since 2017, JAMSTEC also began releasing images of debris gathered over more than 30 years by "Shinkai 6500" and "Shinkai 2000," through the Deep-sea Debris Database. As the first database of its kind in the world, it is expected to be utilized for education on the marine plastics problem, for the media, and for scientific research.

3.4 Regional research institutions

The Kanagawa Prefectural Environmental Science Center conducted a study on the actual situation of floating microplastics along the coast of Sagami Bay from 2017 to 2018.[15] The five coastal locations where the study was conducted were Zushi (Zushi City), Kugenuma (Fujisawa City), Takahamadai (Hiratsuka City), Sanno-amiisshiki (Odawara City), and Kurihama (Yokosuka City). The study was targeted at the two area sections that make up the seashore—the high-water line and the supratidal zone. A square sampling area of 40 cm was designated, and approximately 3 cm of sand was scooped up from the surface and sifted through 4.75 mm mesh to obtain the sand samples. In the laboratory, microplastics were separated using a combination of gravitational sorting which was carried out using water, sifting, and visual sorting. Each individual fragment was viewed through a stereoscopic microscope and classified by shape and color, while material identification was carried out through infrared absorption spectrum. The results showed that the main materials of the floating microplastics were polyethylene (PE), polypropylene (PP), and polystyrene (PS), and clear differences were observed in the material composition and number of drifting pieces in each coastal region.[15]

The Shizuoka Institute of Environment and Hygiene conducted a study in 2018 by collecting sand and seawater samples from Hamatome Coast in Yaizu City, and analyzing the microplastics contained in the samples.[27] A square sampling area of 50 cm was established, and approximately 1 cm of sand was scooped up from the surface and sifted through 4.75

mm mesh to obtain the sand samples. A pump was used to obtain samples from seawater. Seawater was collected from the surface of the sea, and filtered through a plankton net of mesh size 20 μm. Microplastics were separated from the samples through gravitational sorting, sifting, ultrasonic vibration and other means. Material identification was then carried out through Fourier Transform Infrared Spectroscopy. The results showed that microplastics were present in both sand and seawater, and the main materials were PE, PS, and PP.[27]

3.5 Local governments

Japan's local governments are engaged in various activities to address the marine microplastics issue. For example, Kawasaki City engaged Pirika, Inc., an environmental start-up, to conduct a study on the situation of drifting microplastics in a total of 14 locations from August to September 2018, including rivers and ports in Kawasaki City. Using the Albatross (mesh size of the net on the sampling device is 300 μm), a research device developed by Pirika, the sampling device was dropped from a bridge or boat into the water, and the solids filtered out in 3 minutes were collected. The samples were then analyzed by Pirika. The results showed that out of 14 locations, microplastics were detected in 13 locations. The main materials were PE, PP, and PA (polyamide); of these, flat, rod-shaped green fragments made up the largest proportion. Spectral analysis showed that these were pieces of artificial turf. (Public Lab, https://publab.jp/).

Saitama Prefecture commissioned a study to shed light on the situation of microplastics flowing from Saitama Prefecture into the sea through the rivers. The study on microplastics was conducted in 2019 across all areas of the prefecture, by using plankton nets of mesh size 300 μm to collect samples from river water at 10 locations of 5 rivers. Microplastics were detected at all locations, and the main materials were PE, PP, and PS. Fragments made up 74% of all the microplastics, while many of these were "secondary microplastics," crushed pieces of larger fragments of plastic. The main source is considered to be plastic used in everyday life (refer to the website of Saitama Prefecture).

Yokohama City conducted a study on the influent and effluent of three water recycling centers in 2018, with the aim of studying, on a trial basis, the actual situation of microplastics at sewage treatment plants. According to the results, microplastics were detected only from the influent at two of the water recycling centers, and from both influent and effluent at one center. As this was a trial study, it will be vital to put greater effort into the water sampling methods and pretreatment going forward (based on materials from Yokohama City).

3.6 Private corporations

Pirika, Inc., an environmental start-up, provides microplastics survey services as a part of its business, and it is conducting surveys and working to shed light on the actual situation of microplastics in various places, such as rivers and ports, as well as sewage treatment plants. It provides support from survey planning, sampling and extraction of microplastics, analysis of composition and size, determination of route, to result reporting. As explained earlier, Pirika has also developed the Albatross, a proprietary microplastics surveying device. It is a low-cost device that can be used anywhere, and is considered to be more convenient and efficient than the usual method using plankton nets.[28] It also has a system for the efficient management of a vast volume of data on microplastics, which it has made available to external parties. It has undertaken a number of survey projects, including a study of drifting microplastics at 14 locations, including rivers and ports, in Kawasaki City, Kanagawa Prefecture, at the request of the city government. It has also been engaged by organizations such as the Nippon Foundation and the Japan Fund for Global Environment, to conduct studies at 100 locations at rivers, ports, and lakes in 12 prefectures across Japan.

Construction & Environmental Consulting Companies are also interested in the microplastics issue, and are conducting various commissioned studies. For example, since 2016, IDEA Consultants, Inc., has been involved in the establishment of guidelines on monitoring methods for microplastics on the ocean surface. It is also involved in studies on the actual situation of microplastics in rivers, sewage treatment plants, deep seabed sediments, and in the bodies of living organisms.

3.7 Summary

Table 1 provides a brief summary of the general situation with regard to the respective microplastics observation platforms (excluding private corporations). In Japan, the microplastics issue is drawing attention from a wide range of institutions, from the national government to private corporations. In order to understand the actual situation, these organizations are engaged in various observation studies on microplastics. Of these, the Ministry of the Environment, universities, and JAMSTEC are conducing fact-finding studies on microplastics over the long-term, in a wider ocean area. Compared to other organizations, these organizations are considered to have relatively adequate manpower, research funds, and a wealth of knowledge. In contrast, regional research institutes and local governments are engaged in microplastics studies over a shorter term, with a focus on coastal regions or rivers. As these are related to the situation on land, they have the advantage of being able to infer, through identification of the materials, the source and raw material of the microplastics. Private corporations mainly accept commissions from the parent research entity, and play an important role. For this reason, the respective organizations have a mutually complementary relationship.

Table 1 Comparison of the respective microplastics observation platforms

Implementing institution	Study period	Study area	Survey method (sensor)	Mesh size (μm)
Ministry of the Environment	2014~	Surface of sea in offshore areas around Japan・Rivers	Neuston net	350
Kyushu University, Tokyo University of Marine Science and Technology	2016	Surface of sea in the southern North Pacific	Neuston net	300
Tokyo University of Science	2015-2017	23 rivers across Japan	Simplified plankton net	350
Research institute (JAMSTEC)	2019	Surface and seafloor from Ogasawara Islands to Sagami Bay	Neuston net, water sampler, mud sampler	300
	2019-2020	Surface of sea in the western North Pacific	Sampler, Neuston net	Less than 300 (*30,100,300) 335
Kanagawa Prefectural Environmental Science Center	2017-2018	Seashores of coastal areas in Sagami Bay	Sieve	475
Shizuoka Institute of Environment and Hygiene	2018	Seashores and surface of sea at Hamatome Coast, Yaizu City	Sieve Pump	475 20
Kawasaki City	2018	Rivers and ports in Kawasaki City	Albatross	300
Saitama City	2019	Rivers in Saitama Prefecture	Plankton net	300
Yokohama City	2018	Sewage treatment plants in Yokohama City	Net Sieve	300 100-5000

However, looking at the overall picture, studies on microplastics are currently mainly conducted on the surface of seas and rivers, using nets of mesh size 300 μm or higher. Consequently, these studies mostly fail to capture the situation of smaller microplastics (below 300 μm) or microplastics that have sunk to the seafloor.

4. The microplastics issue and outlook for the future

This study reviewed the current status of microplastics studies with a focus on the domestic situation in Japan, but various initiatives are also being carried out overseas. For example, since 2018, the charity organization Just One Ocean (UK) and the University of Portsmouth planned a project titled “The Big Microplastic Survey,” and is promoting activities to collect basic data on microplastics from rivers and coasts around the world, through interested participants including groups, organizations, and individuals.[29] China, led by the State Oceanic Administration, has been monitoring the microplastics situation from coastal regions to open seas, and even to the polar regions, since 2016. Also, the Marine Waste and Microplastic Research Center was established by the National Marine Environmental Monitoring Center in 2017 to provide various forms of research support, including survey methods, technology, and management measures pertaining to microplastics.

To resolve the marine microplastics issue, it is first vital for countries around the world to cooperate in understanding the actual situation of microplastics. However, collection and quantification methods for microplastics are still not standardized and unified across the world. In order to advance the standardization of microplastics collection and quantification methods, it is important to promote further international collaborative research and exchanges.

According to existing literature, 99% of the plastics drifting in the oceans is lost from the surface, creating the problem of "missing plastic."[30] The reason for the missing plastic is, first, because plastics are observed only in limited sea areas.; second, much of the observation data is for plastics larger than 300 μm, while the data on smaller ones are limited; third, few monitoring surveys are implemented on the seafloor or in water columns.

To address this issue of "missing plastic," JAMSTEC began conducting a study on the situation of plastics in the deep sea from 2019, using the "Shinkai 6500" and Free-fall Camera System. Furthermore, with assistance from the Environment Research and Technology Development Fund disbursed by the Ministry of the Environment, since 2018, Professor Tadashi Tokai from Tokyo University of Marine Science and Technology has been working on the establishment of sampling methods for fine microplastics (below 350μm) drifting in the sea, by depth from the surface to the water columns, using multilayered nets, as well as the establishment of basic technology for the automatic detection of microplastics in seabed sediments. The Nippon Foundation and the University of Tokyo launched a joint research project in 2019 titled "Research Project on Marine Plastics." Under this project, they are going to study the vertical distribution of microplastics obtained from the surface to the seafloor in the oceans or in bays. Furthermore, from 2020, Nippon Yusen has plans to collect microplastics samples during the navigation of its vessels by utilizing its in-house network of approximately 750 ships in service. The samples will be analyzed by the Chiba Institute of Technology, and a detailed global map of plastic waste will be drawn up based on this, shedding light on the geographical information, sizes, distribution density, and temporal changes of microplastics.[31]

It is difficult to recover microplastics as they are not directly visible to us. They are constantly flowing with the currents and waves, ingested by marine organisms, and sinking into the deep sea. For this reason, it is difficult to conduct a comprehensive survey across a wide area. Going forward, in addition to advancing observation studies on microplastics in deeper and wider sea areas, it is necessary to elucidate their distribution and movement in the oceans, and to draw up a numerical model. The research by Kyushu University's Professor Isobe and his team, which aims to build a plastic circulation model on a global scale, is a good example of this. By combining field surveys with theoretical methods, we will be able to move closer to solving the problem of microplastics in the oceans.

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