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1 Title

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16 Abstract

17 Sampling was conducted at 31 sites in the western Pacific Ocean from 2000 to 2001 with the aim of
18 collecting plastic fragments with a neuston net (mesh size: 1.00 mm × 1.64 mm). Small plastic fragments
19 including microplastics (small fragments in the size range of 1.1–41.8 mm) were collected at multiple survey
20 sites. Waters with high densities of small fragments were observed between 20°N and 30°N to the south of
21 Japan and between 20°S and 30°S to the northeast of New Zealand (maxima of 6.63×10^2 and 2.04×10^2
22 pieces/ha, respectively). These waters are located to the west of the Ekman convergence zones related to
23 trade winds in the subtropical gyres of the North and South Pacific Oceans. Nearly no small plastics were
24 observed in the tropical circulation of the western Pacific Ocean.

25 (136 words)

26

27 Keywords: Western Pacific Ocean, microplastics, mesoplastics, subtropical gyre, tropical circulation

28

29 Small plastic fragments including plastic resin pellets that drift in the ocean have attracted attention since
30 the 1970s due to their ability to adsorb and transport persistent organic pollutants [1, 2]. Previous surveys
31 conducted in Tokyo Bay and Sagami Bay suggested that the plastic resin pellets found in the ocean were
32 originated from the land [3]. Microplastics, which are derived from mismanaged plastic wastes discharged
33 into the ocean and are degraded into small fragments by exposure to ultraviolet radiation and mechanical
34 erosion, have also attracted considerable attention [4]. The amount of these small plastic fragments is
35 particularly high in the East Asian seas, including those around Japan [5]. The environmental risk of these
36 small plastic fragments arises partly from their ingestion by marine organisms; moreover, recent studies have
37 found ingested plastic fragments in a variety of marine organisms [6-8]. Although previous microplastic
38 surveys have been conducted in the five gyres and marginal seas, surveys in the tropical waters of the Pacific
39 Ocean are not yet sufficient [5, 8-10]. In addition, microplastic, which is now regarded as an oceanic
40 pollutant, has not been observed operationally; therefore, the archived dataset of plastic fragments in the
41 world's oceans remains quite poor. Mismanaged plastic wastes discharged into the ocean are likely to
42 increase rapidly over the next decade, especially, in East and Southeast Asian countries [11]. The abundance
43 of ocean-borne microplastics in the past provides us with important information to elucidate to what extent
44 small plastic fragments have increased in the oceans in the past and to what extent these fragments will
45 increase in the future.

46 Therefore, we present the abundance of small plastic fragments collected using a neuston net in the pelagic
47 zone of the western Pacific from 2000 to 2001 aboard a training vessel belonging to the Tokyo University of
48 Marine Science and Technology (previously, the Tokyo University of Fisheries). The survey areas (Fig. 1)
49 covered a broad area in the western Pacific; therefore, the data will be useful for comparisons with
50 microplastic abundances observed at nearby locations now and in the future.

51

52 **Materials and Methods**

53 The sampling was performed outside the exclusive economic zones of the surrounding countries during
54 the period from October 2000 to March 2001 by the training vessel, *Umitaka-maru IV*, belonging to the
55 Tokyo University of Marine Science and Technology. Because the primary aim of the survey was to collect
56 small plastic fragments with sizes of a few millimeters including plastic resin pellets, which are regarded as
57 one of the principle plastic polluters, a neuston net with a mouth of 700 mm × 700 mm and a mesh size of
58 1.00 mm × 1.64 mm was used for the surveys. The buoyancy of the net was adjusted such that the upper half
59 the net mouth was exposed above the sea surface while towing approximately 1 m from the port side hull of
60 the ship. The ship speed during towing was maintained at approximately 2–3 knots during each 10 min tow.
61 The start and finish locations of the transects were determined on the basis of the latitude and longitude
62 coordinates measured using a GPS. Sampling was conducted every two days unless towing was difficult due
63 to stormy weather conditions.

64 In the laboratory onboard the ship, the small plastic fragments were immediately spotted with the
65 naked eye and separated from natural materials, including zooplankton, based on shapes and colors in a
66 manner similar to Ogi and Fukumoto [1]. The plastic fragments were then counted and photographed using a
67 digital camera. The material composition of the collected plastic fragments was not determined in this study.
68 After the voyage, the length of the longest axis of each fragment was measured from the digital photographs.
69 The fragments were classified according to their shapes, such as granular, sheet-like, string-like, based on the
70 photographs. For this study, the volume of seawater passing through the net could not be calculated because a
71 flow meter was not installed at the mouth of the net. Therefore, the filtered area was estimated on the basis of
72 the width of the net mouth and the towing distance, which was determined using the GPS data. In the
73 procedure used to measure the small plastic fragments, the “distribution density” of the fragments was
74 defined as the number of fragments per unit area with units of pieces/ha (ha = 10⁴ m²).

75

76 **Results**

77 In total, sampling was conducted at 31 stations: 9 stations between Tokyo and New Caledonia (Stns. 1–9),
78 2 stations between New Caledonia and New Zealand (Stns. 10 and 11), 6 stations between New Zealand and
79 Tahiti (Stns. 12–17), 12 stations between Tahiti and Hawaii (Stns. 18–29), and 2 stations between Hawaii and
80 Tokyo (Stns. 30–31). The locations of Stn. 20–26 were crowded because they were conducted in conjunction
81 with operations with tuna longline fisheries. Small plastic fragments were collected at 15 of 31 stations (see
82 Fig. 1 and Table 1 for the distribution density at each station). Figure 2 shows photographs of all the
83 fragments collected at each station. Every plastic particle appeared to be a fragment or plastic fiber derived
84 from the breakdown of larger plastic products. No virgin plastic pellets, such as disc- or cylindrical-shaped
85 plastic resin pellets, were found in the collected plastic fragments (Fig. 2). Granular fragments were the most
86 commonly collected, comprising 67% of the total (Fig. 2 and Table 1). The greatest variety of plastic
87 fragment shapes was found at Stn. 1.

88 The highest distribution density was also found at Stn. 1, closest to Japan (6.63×10^2 pieces/ha). At Stn. 1,
89 a roll of plastic tape was found together with plastic fragments, as shown in Fig. 2 (the red piece in Stn. 1);
90 however, these fragments were excluded from the analysis because they were not categorized as “small
91 plastic fragments,” the objective of the study. The distribution density decreased moving southward from the
92 mid-latitude in the Northern Hemisphere to the equator, and the small plastic fragments disappeared at Stns.
93 7–9 in the Southern Hemisphere beyond the equator. However, in the Tasman Sea, plastic fragments with a
94 density of 2.24×10^2 pieces/ha were again collected at Stn. 10. Furthermore, between New Zealand and
95 Tahiti, a distribution density of 5.0×10^2 pieces/ha was observed at Stn. 12 northeast of New Zealand. The
96 highest density of small plastics observed in the Southern Hemisphere was 2.03×10^2 pieces/ha, which was
97 recorded at Stn. 14 further northeast of New Zealand. The density was relatively low (6.3×10 pieces/ha) at

98 Stn. 15. In addition, no small plastic fragments were collected to the north of Stn. 16 in the Southern
99 Hemisphere. At Stn. 25 in the Northern Hemisphere between Tahiti and Hawaii, only burned fragments of a
100 petrochemical material were collected (see Fig. 2). A density of 1.8×10 pieces/ha was recorded at Stn. 29 to
101 the south of Hawaii, and the density tended to increase from Hawaii (Stn. 30: 2.9×10 pieces/ha) toward
102 Japan (Stn. 31: 1.64×10^2 pieces/ha). As aforementioned, 67% of the fragments collected in this study had a
103 granular shape, and a relatively large amount of granular-shaped fragments was observed over the entire
104 study area (see Table 1).

105 The sizes of the small plastic fragments were determined by their length along their longest axis, and their
106 size range was from 1.1 to 41.8 mm with an average of 5.7 mm and a median of 3.6 mm (Fig. 3).
107 Approximately 70% of the fragments were categorized as microplastics, defined as plastic fragments with a
108 size smaller than 5 mm [12]. No fragments smaller than 1 mm were collected due to the net mesh size of
109 $1.00 \text{ mm} \times 1.64 \text{ mm}$ (Fig. 3). The mean sizes of the fragments collected in the Northern and Southern
110 hemispheres had no significant statistical difference ($t = 0.24, p > 0.05$).

111 **Discussion**

112 In this survey, high densities of small plastic fragments (>50 pieces/ha) were observed in the waters from
113 $20^\circ 0' \text{ N}$ to $29^\circ 10' \text{ N}$ to the south of Japan and from $27^\circ 8' \text{ S}$ to $32^\circ 36' \text{ S}$ to the northeast of New Zealand.
114 There are surface convergence regions in the subtropical gyres in the North Pacific, South Pacific, North
115 Atlantic, South Atlantic, and Indian oceans [8]. The convergence of floating marine debris in these waters
116 occurs due to a similar mechanism: floating marine debris converge toward a mid-latitude belt by the Ekman
117 flows and then move further eastward by geostrophic currents to form a high-density region [13, 14]. The
118 high densities of plastic fragments observed in both the North and South Pacific oceans were located in the
119 western areas of the subtropical convergence regions in the mid-latitudes [8]. However, floating marine
120 debris in equatorial waters is likely to be continually transported westward in the absence of a convergence

121 zone until the debris reaches to the east of the Philippines and the Indonesian archipelago due to the
122 Equatorial currents (Kubota et al. [14] for the argument for the Northern Hemisphere). In fact, except for the
123 burned fragments collected at Stn. 25, practically, no small plastic fragments were collected over the tropical
124 waters in the presented survey (Stns. 7–9 and 18–28). The burned petrochemical fragments collected at Stn.
125 25 might have been released from one of the tuna longline fishing vessels operating in the vicinity. Jembeck
126 et al. [11] suggested that some countries in East and Southeast Asia discharge a large amount of mismanaged
127 plastic wastes into the ocean and Isobe et al. [5] demonstrated that the waters around Japan downstream of
128 these countries were a hot spot for pelagic microplastic due to the Kuroshio Current [5]. This suggests that
129 microplastics may flow into the North Pacific from this hot spot.

130 The mode of the fragment size observed in this study was approximately 3 mm. The abundance of the
131 fragments decreased as they become smaller than the mode size, and no fragments with a size ≤ 1 mm were
132 collected (Fig. 3). As aforementioned, this may have been caused in part by the relatively coarse mesh size of
133 the neuston net (1.00 mm \times 1.64 mm). In addition, the usage of a stereomicroscope rather than the naked eye
134 to extract the small plastic fragments might have increased their numbers, especially, in size ranges smaller
135 than 3 mm. Neuston nets with a mesh size of 0.333 mm have been used for microplastic surveys in recent
136 years [5, 15]. In those studies (e.g., Isobe et al. [5] and Isobe et al. [16]), the mode in the longest axis length
137 was in the vicinity of 1 mm, and a large amount of microplastics smaller than 1 mm was also collected.
138 According to Eriksen et al. [9], approximately 40% of the plastic fragments had sizes smaller than 1 mm in
139 their survey conducted in the eastern South Pacific in 2011. Consequently, the distribution densities of
140 microplastics in the presented study were potentially underestimated. Therefore, it is not possible to make an
141 in-depth examination of microplastic behaviors such as their vertical distribution (e.g., Kukulka et al. [17]);
142 this will be explored in a future study.

143 The presented study provides an overview of the distribution of small plastic fragments in the western

144 Pacific Ocean from 2000 to 2001. However, future studies will need to employ neuston nets equipped with a
145 flow meter and a finer mesh size, as seen in recent studies. Note that the distribution densities computed in
146 the presented study might not be directly comparable to other microplastic data obtained under different
147 wind/wave conditions. This is because the density of lightweight microplastics drifting in the surface layer
148 rapidly decreases (increases) in the high (low) vertical mixing under stormy (calm) oceanic conditions.
149 Vertically integrating the densities at depth yields the microplastic number for the entire water column;
150 therefore, this value is required for comparisons with other microplastic data collected under other oceanic
151 conditions irrespective of vertical mixing. Such a “vertical correction” should be performed on the fragment
152 abundance obtained in the presented study using archived wave/wind data. Recently, a survey of small
153 plastic fragments in conjunction with the sequential monitoring of wind/waves was conducted by the T/V
154 *Umitaka-maru* along a track from the Antarctic Ocean to Tokyo during the period of February–March 2016.
155 These surveys included sampling in the vicinity of Stns. 1–11 of this study; therefore, we can demonstrate
156 changes in the distribution densities, sizes, and shapes of small plastic fragments over the past 15 years.

157

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163

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208

209 **Figure captions**

210

211 Fig. 1. Sampling locations and the distribution density (see the text for the definition) of small floating plastic
212 fragments at each station (pieces/ha).

213

214 Fig. 2. Photographs of the small floating plastic fragments collected at each station.

215

216 Fig. 3. Frequency distribution of the longest-axis length of the plastic fragments collected by visual
217 identification. Plastic fragments with a long axis <5 mm accounted for 70% of the collected samples.