THE QUANTITATIVE DISTRIBUTION AND CHARACTERISTICS OF NEUSTON PLASTIC IN THE NORTH PACIFIC OCEAN, 1985-88

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ABSTRACT

The distribution, abundance, and characteristics of neuston plastic in the North Pacific, Bering Sea, and Japan Sea were studied during the 4-year period 1985-88 at 203 neuston stations encompassing ca. 91,000 m^2 of sampling. The highest total density of neuston plastic was 316,800 pieces/km^2 at lat. 35°59'N, long. 152°00'E in Transitional Water east of Japan. The highest total concentration of neuston plastic was 3,491.8 g/km^2 at lat. 40°00'N, long. 171°30'E near the Subarctic Front in the central North Pacific. Main types of neuston plastic were miscellaneous line fragments (21.7% of all stations), Styrofoam (12.8%), polypropylene line fragments (7.4%), miscellaneous or unidentified plastic (7.4%), and raw pellets (5.9%). Plastic fragments were recorded at 52.2% of all stations and at 88.3% of those stations with plastic. The highest densities (number per square kilometer) and concentrations (gram per square kilometer) of neuston plastic occurred in Japan Sea/nearshore Japan Water, in Transitional Water, and in Subtropical Water. Densities of neuston plastic in Subarctic Water and Bering Sea Water were low. Heterogeneous geographic input and currents and winds are important in distributing and concentrating neuston plastic. Microscale convergences appear to be important mechanisms that locally concentrate neuston plastic, increasing the probability of its entering food chains.

In R. S. Shomura and M. L. Godfrey (editors), Proceedings of the Second International Conference on Marine Debris, 2-7 April 1989, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-154. 1990.

INTRODUCTION

Marine debris, especially plastic debris, increasingly is recognized as a national and international pollution problem (Shomura and Yoshida 1985; Wolfe 1987). Plastic enters the ocean in many forms and many sizes. In addition to plastic objects associated with ships (e.g., lines, nets, floats), virtually every kind of plastic packaging and plastic object used on land may be discarded or lost to the sea. Some plastics are denser than seawater and thus sink, but some are buoyant enough to float, either because of trapped gas or because of low specific gravity. At sea, plastic objects undergo mechanical breakdown or fragmentation, leading to progressively smaller pieces of floating plastic. The size fraction of plastic debris caught in nets designed to catch surface plankton (hereafter referred to as neuston plastic) is of interest for several reasons. First, small plastic objects are more abundant than are the larger ones from which they are formed. Second, collection of plastic in nets is an objective process that provides unbiased estimates of densities. Finally, objects in this size range can be mistaken for food items, with possibly important ecological consequences (Day 1980; Day et al. 1985).

Several workers have investigated the distribution of neuston plastic in the North Pacific (Wong et al. 1974; Shaw 1977; Shaw and Mapes 1979; Day et al. 1985; Day and Shaw 1987). These studies have shown that neuston plastic is widespread, is most abundant in the central and western North Pacific, and is distributed by currents and winds.

The goal of this study was to improve our knowledge of the quantitative distribution and characteristics of neuston plastic in the North Pacific Ocean. Specifically, we wanted to: (1) describe the quantitative distributions of the main types of neuston plastic, (2) compare the at-sea densities of the main neuston types, (3) describe the frequencies of colors of neuston plastic, and (4) examine the importance of currents and winds in affecting the quantitative distribution of neuston plastic. Because of the extensive geographic coverage of the work, this study provides one of the most detailed synoptic pictures of neuston plastic anywhere in the world ocean.

METHODS

We collected data on the density, concentration, and types of neuston plastic $\geq$0.500 mm in size at 203 neuston stations in the North Pacific Ocean north of lat. 21°N (i.e., Hawaii) and in the Bering and Japan Seas. At each station, a 1.3-m ring net (during 1985) or a Sameoto (Sameoto and Jaroszynski 1969) neuston sampler (1986-88) with a 0.500-mm mesh net was used to collect neuston samples. Following Day and Shaw (1987), the area of ocean's surface sampled was calculated by multiplying the width of the net opening (0.5 m for the Sameoto sampler; see Day and Shaw 1987 for information on the ring net) by the distance the ship traveled in 10 min of sampling at a known speed, corrected for the time that the net was not fishing. Samples were washed from the net and either were sorted on the ship or were preserved in formalin and sorted later in the laboratory. Although areas sampled varied among stations, we ignored these differences among stations in the analyses. Data from 1985 that already were published (32 stations, Day and Shaw 1987) were included here because that number is small compared with the 171 stations for which the data have not been published.

During sorting, individual pieces of plastic were counted and identified as one of six standardized types: pellet, fragment, Styrofoam (which may include foamed plastics of other chemical composition), polypropylene line (which may include synthetic line of other chemical composition), miscellaneous or unidentified line, and miscellaneous or unidentified plastic. These pieces of plastic also were identified as 1 of 11 standardized colors: black/gray, blue, brown, green, orange, red/pink, tan, transparent, white, yellow, and mixed or unidentified. The samples then were placed in preweighed vials and were air-dried before being weighed to the nearest 0.001 g.

Data were compiled as the total density (number per square kilometer) and total concentration (mass per square kilometer) of neuston plastic at each station and as the density of each general type of plastic at each station. The color data were compiled as the numbers and frequencies of occurrence of each color at each station and were tabulated as total frequencies of each color. For data analysis, each station was stratified geographically into one of five water masses: Bering Sea Water, Subarctic Water (north of the Subarctic Front, or north of ca. lat. 42°N), Subtropical Water (south of the Subtropical Front, or south of ca. lat. 31°N), Japan Sea/nearshore Japan Water (the latter area consisting of water east of Japan and west of lat. 150°E), and Transitional Water (that between Subarctic Water and Subtropical Water, and including the Subarctic Frontal Zone, the Transition Zone, and the Subtropical Front).

The stratified data on total density, total concentration, and densities of each type of neuston plastic were analyzed with a Kruskal-Wallis test (Conover 1980; Zar 1984). For each data set, we tested the hypothesis:

H_0: The density (or concentration) does not differ among water masses.

When test results were significant, we conducted multiple comparisons tests (Conover 1980) to determine which water masses were different. We also calculated means and standard deviations of each data set in each water mass. The color data were compiled as frequencies of each color of plastic. Subsequently, these frequencies were divided by the total number of plastic items to determine percentages of each color type.

RESULTS

Neuston plastic was recorded at 120 stations (59.1% of total stations); the total number of pieces recorded was 1,774. The two water masses in which plastic occurred at 100% of the stations were Subtropical Water ($n = 2$ stations) and Japan Sea/nearshore Japan Water ($n = 11$ stations). Neuston plastic also was common in Transitional Water, where it occurred at 56 (93.3%) of 60 stations, and in Subarctic Water, where it occurred at 46 (71.9%) of 64 stations. Finally, it was uncommon in Bering Sea Water, where it occurred at only 5 (7.6%) of 66 stations.

Total Density

Total densities of neuston plastic were highest in the Japan Sea, in nearshore water east of Japan, and in Transitional Water and the Subarctic Front; total densities generally were very low in Subarctic Water (especially in the center of the Alaska Gyre) and in the Bering Sea (Fig. 1). The highest total density of neuston plastic was 316,800 pieces/km^2 at lat. 35°59'N, long. 152°00'E in Transitional Water east of Japan. Other stations with high total densities were 221,000 pieces/km^2 at lat. 38°55'N, long. 135°58'E in the Japan Sea; 217,300 pieces/km^2 at lat. 37°58'N, long. 52°00'E near the Subarctic Front east of Japan; and 202,700 pieces/km^2 at lat. 40°00'N, long. 174°30'E near the Subarctic Front in the central North Pacific. Total densities differed significantly among water masses ($H = 1221.482$; $n = 203$; $df = 4$; $P < 0.05$; Table 1). Multiple comparisons indicated that densities were: Japan Sea/nearshore Japan Water = Subtropical Water = Transitional Water > Subarctic Water > Bering Sea Water.

Concentration

Total concentrations of neuston plastic generally were low, with high concentrations recorded at only four stations in Transitional Water, at two stations in nearshore water east of Japan, and at one station in Subarctic Water; total concentrations at the other stations with plastic generally were <10% of the highest concentration (Fig. 2). The highest total concentration was 3,941.8 g/km^2 at lat. 40°00'N, long. 171°30'E near the Subarctic Front in the central North Pacific. Other concentrations >1,000 g/km^2 were 3,007.9 g/km^2 at lat. 37°58'N, long. 152°00'E near the Subarctic Front east of Japan, 1,979.1 g/km^2 at lat. 35°59'N, long. 152°00'E in Transitional Water east of Japan, and 1,048.5 g/km^2 at lat. 28°20'N, long. 162°20'W in Subtropical Water north of the Hawaiian Islands. Total concentrations differed among water masses ($H = 120.604$; $n = 203$; $df = 4$; $P < 0.05$; Table 1). Multiple comparisons indicated that concentrations were: Subtropical Water = Japan Sea/nearshore Japan Water = Transitional Water > Subarctic Water > Bering Sea Water. The similarity in patterns between total densities and total concentrations is understandable, considering the strong correlation between these two parameters (Spearman's $R = 0.905$; $Z = 12.861$; $n = 203$; $P < 0.05$; Conover 1980; Zar 1984). The Pearson's product-moment correlation between these parameters was not as high, however ($r = 0.544$; $n = 203$; $P < 0.05$).

Pellets

In the plastics industry, plastic resins commonly are manufactured as cylindrical pellets a few millimeters in size. Later, these pellets are melted and molded into finished products. Pellets were uncommon, being recorded only 12 times (5.9% of total stations and 10.0% of stations with plastic). Pellets were absent in the Bering and Japan Seas, were recorded only once in Subarctic Water, and were recorded primarily in Transitional

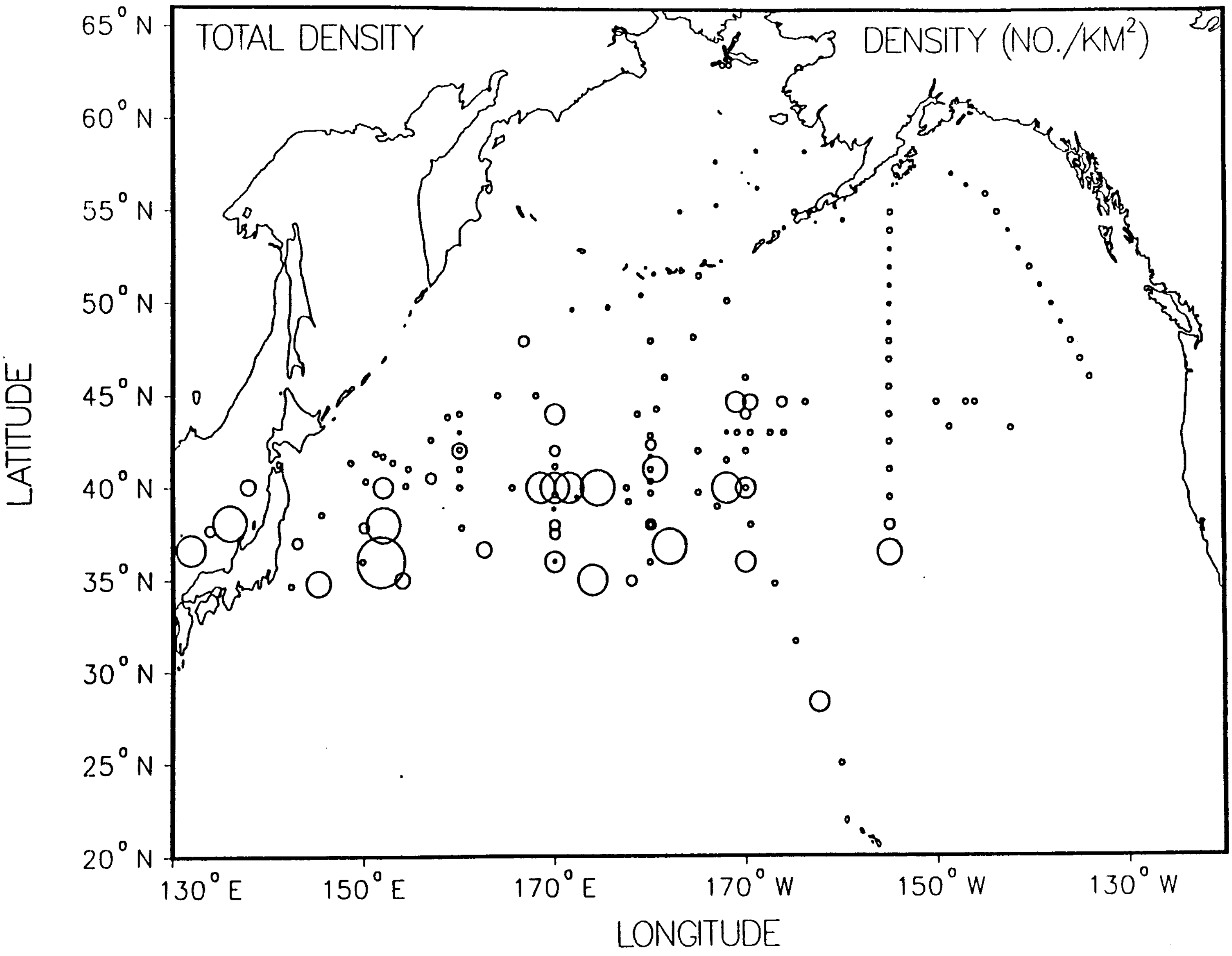

Figure 1.--Total densities of neuston plastic, 1985-88. Solid black circles indicate stations at which neuston plastic was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 316,800 pieces/km^2.

Table 1.--Densities (number per square kilometer) and concentrations (grams per square kilometer) of neuston plastic in five water masses of the North Pacific, 1985-88.

Parameter	Bering Sea Water		Subarctic Water		Transitional Water		Subtropical Water		Japan Sea and nearshore Japan Water	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Number	66		64		60		2		11	
Area sampled (m^2)	35,906		28,662		22,154		541		3,824	
Total concentration	1.0	4.2	61.4	225.5	291.6	714.4	535.1	726.1	128.2	172.2
Total density	100	600	12,800	22,300	57,900	72,800	61,000	74,000	74,700	73,800
Pellet	0	0	<100	300	300	800	3,300	4,600	500	1,200
Fragment	0	0	9,600	20,300	52,700	69,200	57,700	69,400	46,100	40,000
Styrofoam	0	0	400	1,300	1,100	3,200	0	0	26,200	37,200
Polypropylene line	100	400	400	1,500	500	1,500	0	0	0	0
Miscellaneous line/thread	100	300	2,600	6,900	2,300	4,600	0	0	1,900	3,300
Miscellaneous/unidentified	100	500	100	500	1,000	3,100	0	0	0	0

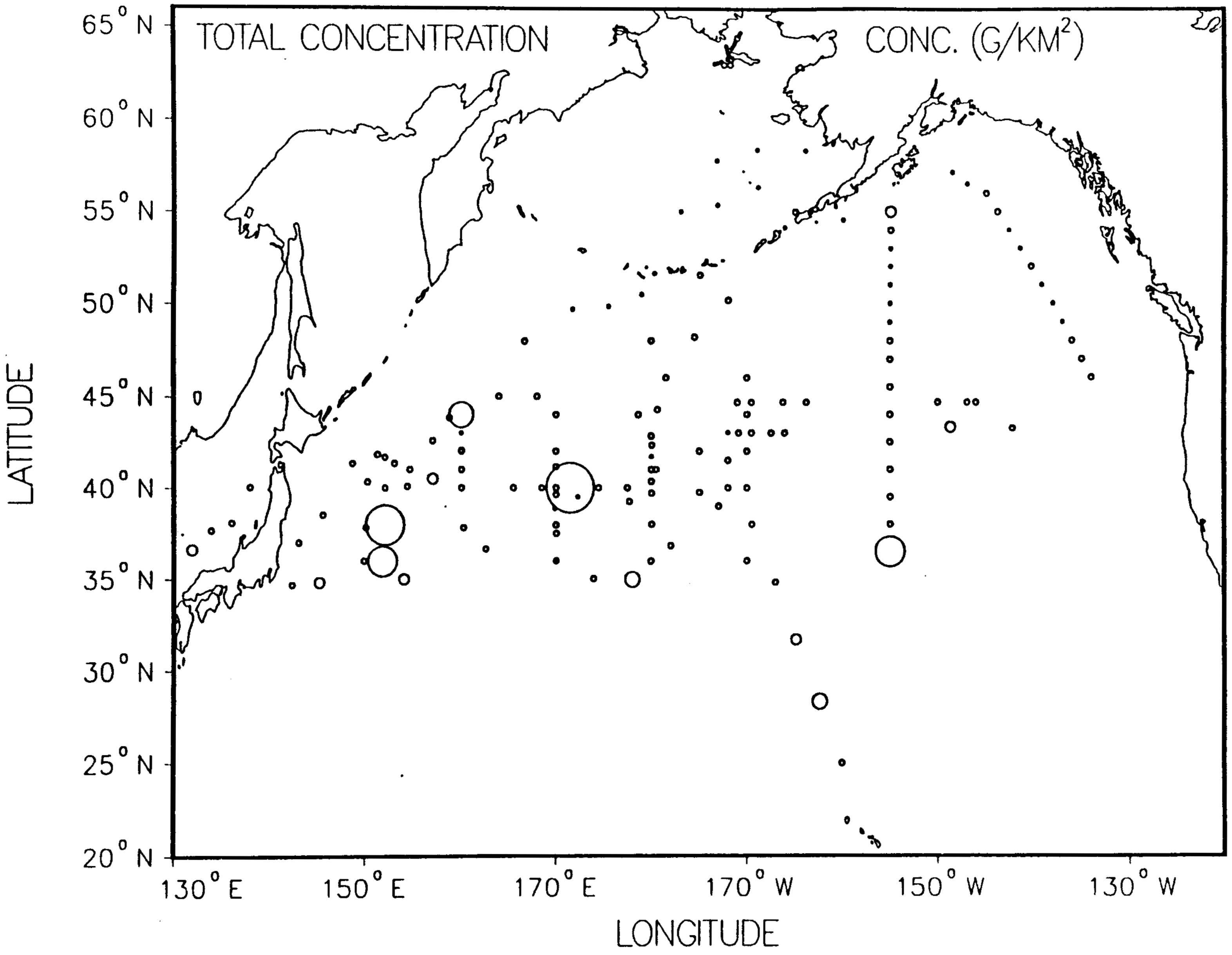

Figure 2.--Total concentrations of neuston plastic, 1985-88. Solid black circles indicate stations at which neuston plastic was not recorded. Sizes of hollow circles indicate relative densities. The highest concentration was 3,941.8 g/km^2.

Water and in nearshore water east of Japan (Fig. 3). The highest density was 6,500 pieces/km^2 at lat. 28°20'N, long. 162°20'W in Subtropical Water north of the Hawaiian Islands. The density of pellets differed among water masses ($H = 22.996$; $n = 203$; $df = 4$; $P < 0.05$; Table 1). Multiple comparisons were confusing, however, in that none of the individual water masses were significantly different. We suspect that the significant result was an artifact of the presence of pellets at both of the two stations in Subtropical Water. Consequently, the mean rank in this water mass was much higher than those in the other water masses, although the small sample size made it impossible to prove that significant differences actually existed.

Fragments

Fragments are small pieces of plastic broken from larger pieces (excluding Styrofoam). This category included primarily chips and pieces of sheets. Fragments were common, being recorded at 106 stations (52.2% of total stations and 88.3% of all stations with plastic). Fragments were common except in the Bering Sea and occurred in highest densities in nearshore water east of Japan and in and around the Subarctic Front; densities were lower in the Japan Sea and Subtropical Water and were much lower in Subarctic Water (Fig. 4). The highest density was 288,000 pieces/km^2 at lat. 35°59'N, long. 152°00'E in Transitional Water east of Japan. Other stations with high densities of fragments were 202,700 pieces/km^2 at lat. 40°00'N, long. 174°30'E near the Subarctic Front in the central North Pacific; and 199,000 pieces/km^2 at lat. 37°58'N, long. 152°00'E near the Subarctic Front east of Japan. The density of fragments differed significantly among water masses ($H = 113.587$; $n = 203$; $df = 4$; $P < 0.05$; Table 1). Multiple comparisons indicated that densities were: Japan Sea/nearshore Japan Water = Subtropical Water = Transitional Water > Subarctic Water > Bering Sea Water.

Styrofoam

This category included all pieces of pieces of foamed plastic; based on observed color and texture, we believe that all of this plastic was polystyrene. Styrofoam was uncommon, being recorded only 26 times (12.8% of total stations and 21.7% of stations with plastic). It was recorded in all locations except the Bering Sea and Subtropical Water, and occurred in highest densities in the Japan Sea and nearshore water east of Japan. It was a "transitional/nearshore Japan species," being recorded outside of this area only five times (Fig. 5). The highest density was 99,500 pieces/km^2 at lat. 36°37'N, long. 131°54'E in the Japan Sea. Other stations with high densities were 82,200 pieces/km^2 at lat. 38°55'N, long. 135°58'E in the Japan Sea; and 65,400 pieces/km^2 at lat. 34°49'N, long. 144°55'E off the eastern coast of Japan. Densities of Styrofoam differed significantly among water masses ($H = 52.967$; $n = 203$; $df = 4$; $P < 0.05$; Table 1). Multiple comparisons indicated that densities were: Japan Sea/nearshore Japan Water > Transitional Water = Subarctic Water = Subtropical Water.

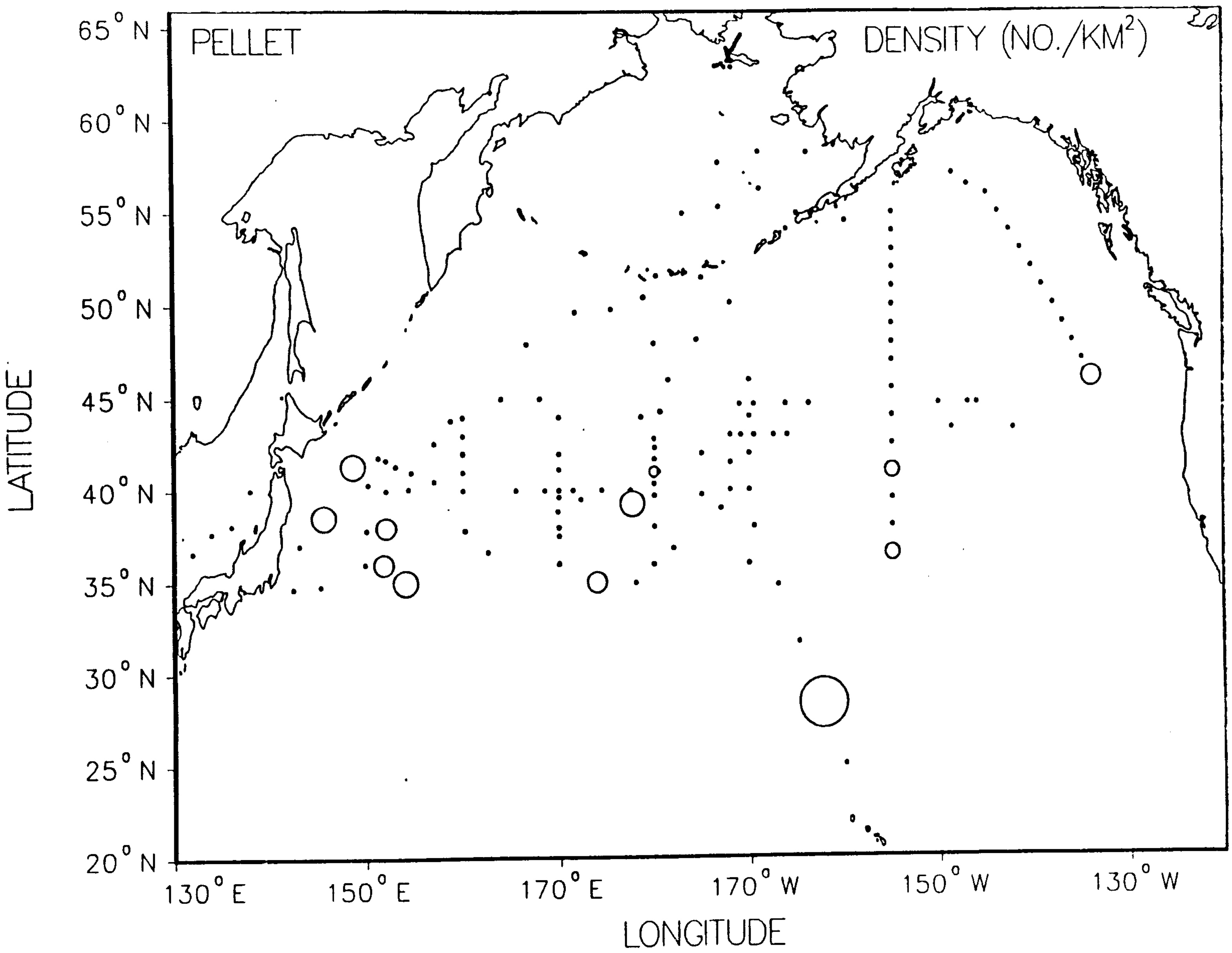

Figure 3.--Densities of pellets, 1985-88. Solid black circles indicate stations at which neuston plastic was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 6,500 pieces/km^2.

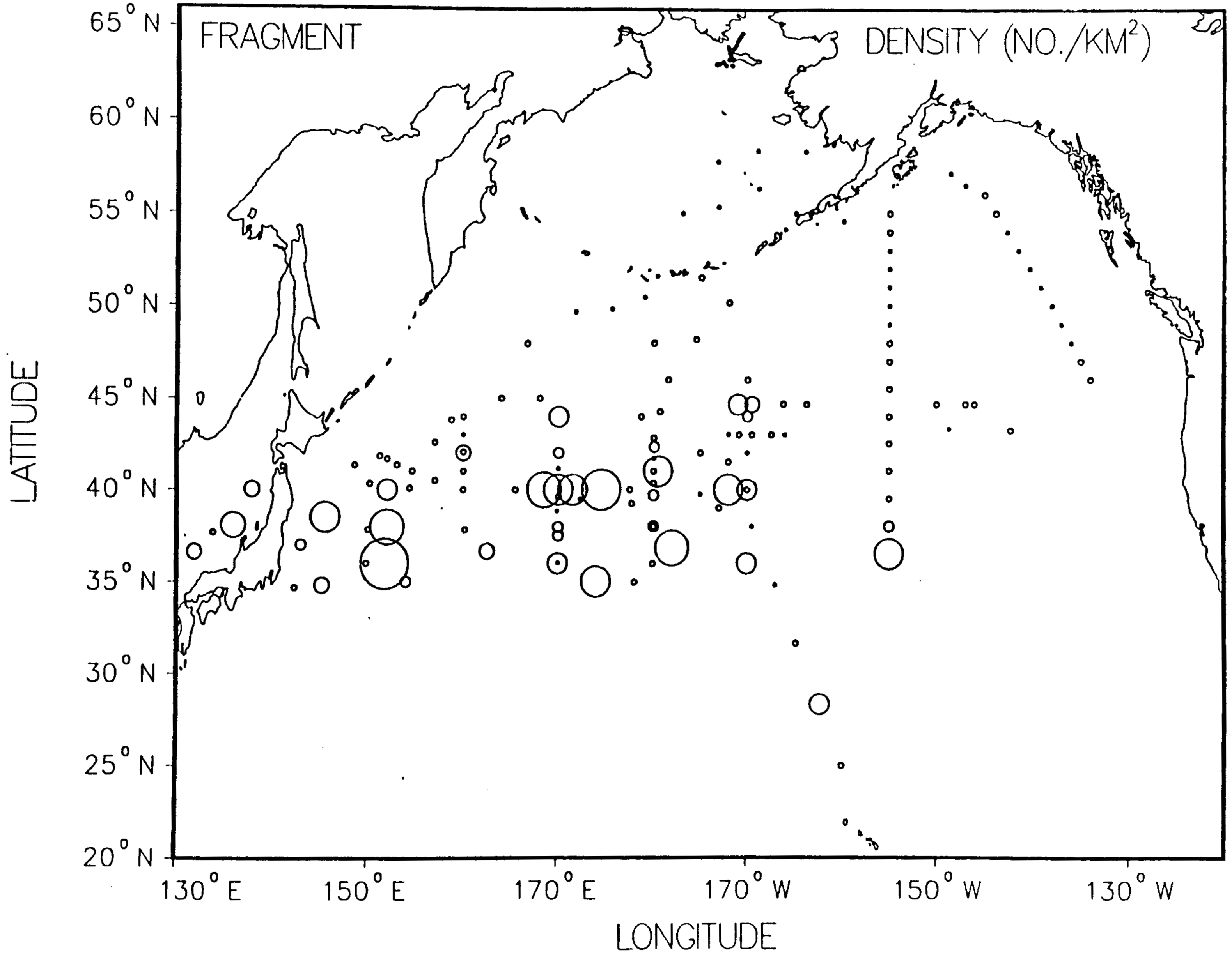

Figure 4.--Densities of fragments, 1985-88. Solid black circles indicate stations at which neuston plastic was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 288,000 pieces/km^2.

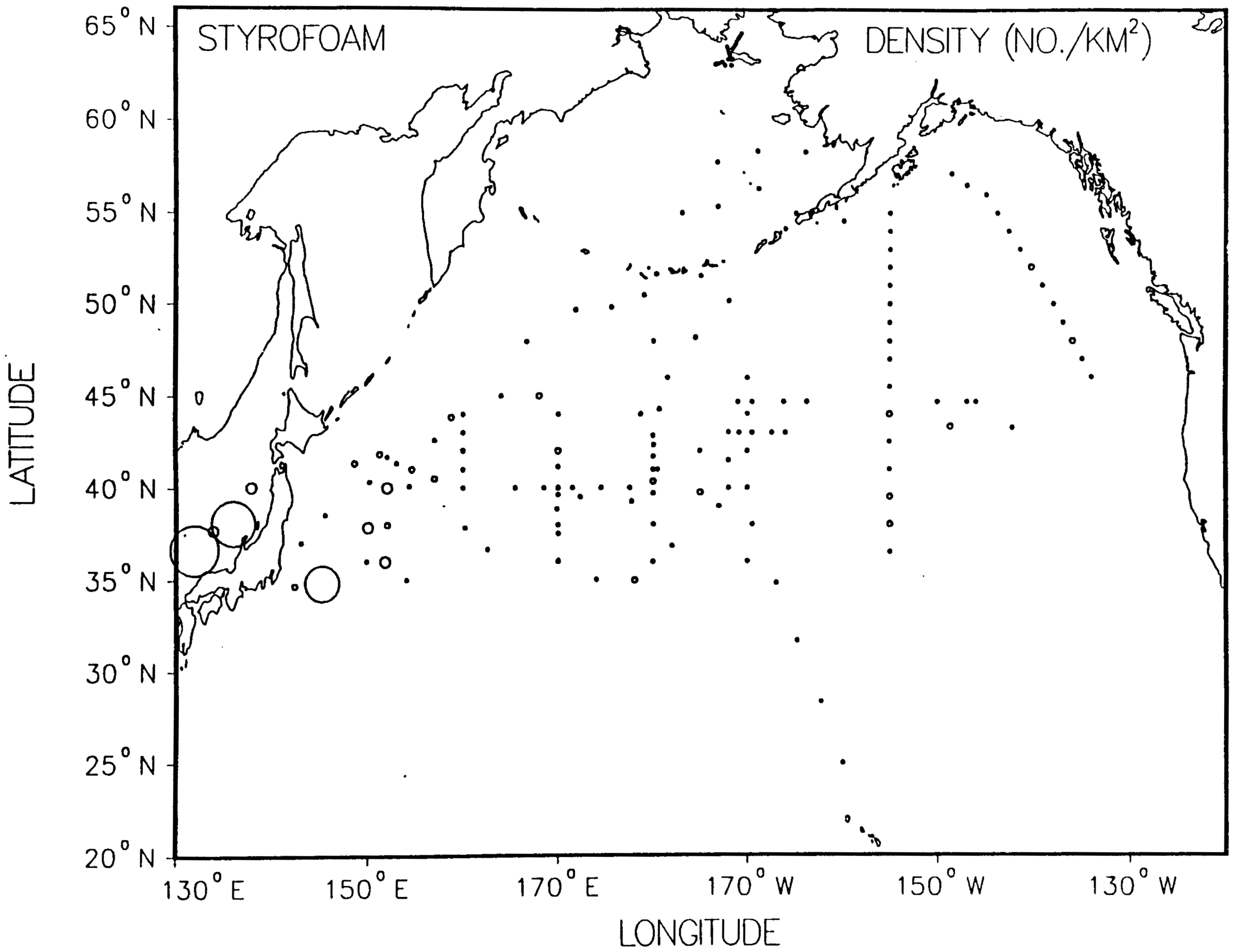

Figure 5.--Densities of Styrofoam, 1985-88. Solid black circles indicate stations at which neuston plastic was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 99,500 pieces/km^2.

Polypropylene Line Fragments

Polypropylene line fragments are small, woven pieces of large synthetic lines that are used as deck lines on fishing boats and cargo ships. Polypropylene is the most commonly used plastic for these applications. These line fragments were uncommon, being recorded 15 times (7.4% of total stations and 12.5% of stations with plastic). Polypropylene line fragments occurred primarily in and near the Subarctic Front and in Transitional Water; they were absent in the Japan Sea and in Subtropical Water (Fig. 6). The highest density was 8,400 pieces/km^2 at lat. 41°09'N, long. 170°00'E near the Subarctic Front in the central North Pacific. We failed to reject the null hypothesis that the density of polypropylene line fragments did not differ significantly among water masses ($H = 3.597$; $n = 203$; $df = 4$; $P > 0.05$; Table 1), probably because densities were low everywhere.

Miscellaneous Lines/Threads

Miscellaneous lines and threads included unidentified woven line fragments and (especially) monofilament lines that were from either gillnets or monofilament fishing line. We do not know what type of plastic they were, but they probably were not nylon, as it does not float (Carpenter 1976). Miscellaneous lines/threads were somewhat common, being recorded 44 times (21.7% of total stations and 36.7% of stations with plastic). They were recorded in all but Subtropical Water, with the highest densities occurring east of Japan and near the Subarctic Front (Fig. 7); they possibly may be fragments of line used by squid jiggers, which fish in this area. The highest density was 40,500 pieces/km^2 at lat. 47°59'N, long. 166°41'E in western Subarctic Water. Densities of miscellaneous lines/threads differed significantly among water masses ($H = 24.607$; $n = 203$; $df = 4$; $P < 0.05$; Table 1). Multiple comparisons were confusing, however, in that those water masses with the largest difference in mean ranks were not significantly different, whereas water masses with smaller differences in mean ranks were significantly different. The two water masses that were significantly different were Transitional Water > Bering Sea Water, two with large sample sizes (60 and 66, respectively). We suspect that other water masses were different but that sample sizes in most were too small for the multiple comparisons to show significant differences. The pattern of mean ranks (in descending order) was: Japan Sea/nearshore Japan Water, Transitional Water, Subarctic Water, Bering Sea Water, and Subtropical Water.

Colors of Neuston Plastic

Most neuston plastic was transparent. This color was recorded 785 times (44.3% of the total 1,774 pieces and 44.9% of plastic of identified color). White plastic also was abundant, being recorded 610 times (34.4% of the total and 34.9% of plastic of identified color), followed by blue (128 pieces; 7.2% of the total and 7.3% of plastic of identified color), black/gray (74 pieces; 4.2% and 4.2%), green (62 pieces; 3.5% and 3.5%), and tan (45; 2.5% and 2.6%). The colors brown (17 pieces; 1.0% and 1.0%), red/pink (13 pieces; 0.7% and 0.7%), yellow (8 pieces; 0.5% and 0.5%), and orange (5 pieces; 0.3% and 0.3%) were rare in occurrence. Miscellaneous or unidentified colors occurred 27 times (1.5%).

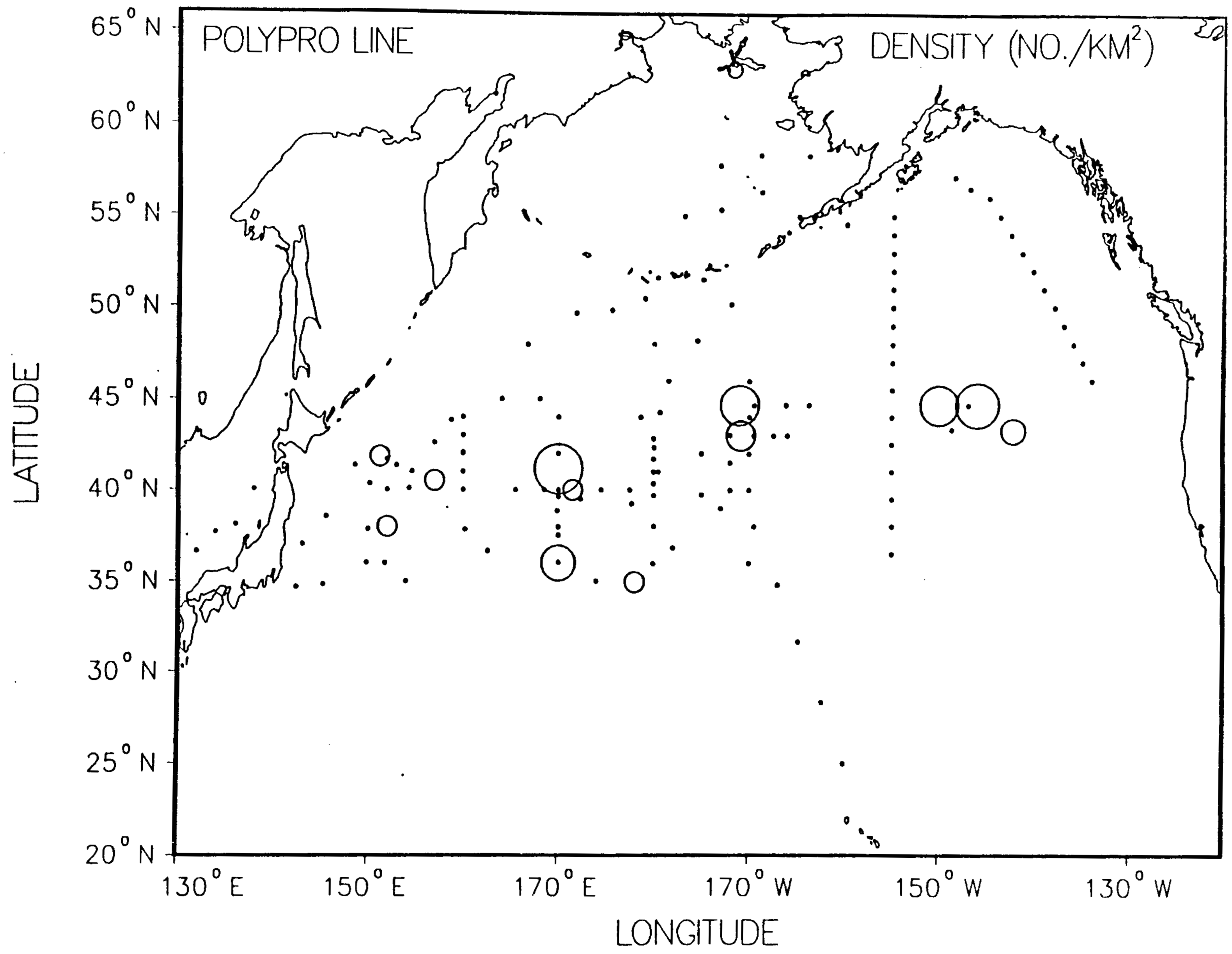

Figure 6.--Densities of polypropylene line fragments, 1985-88. Solid black circles indicate stations at which neuston plastic was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 8,400 pieces/km^2.

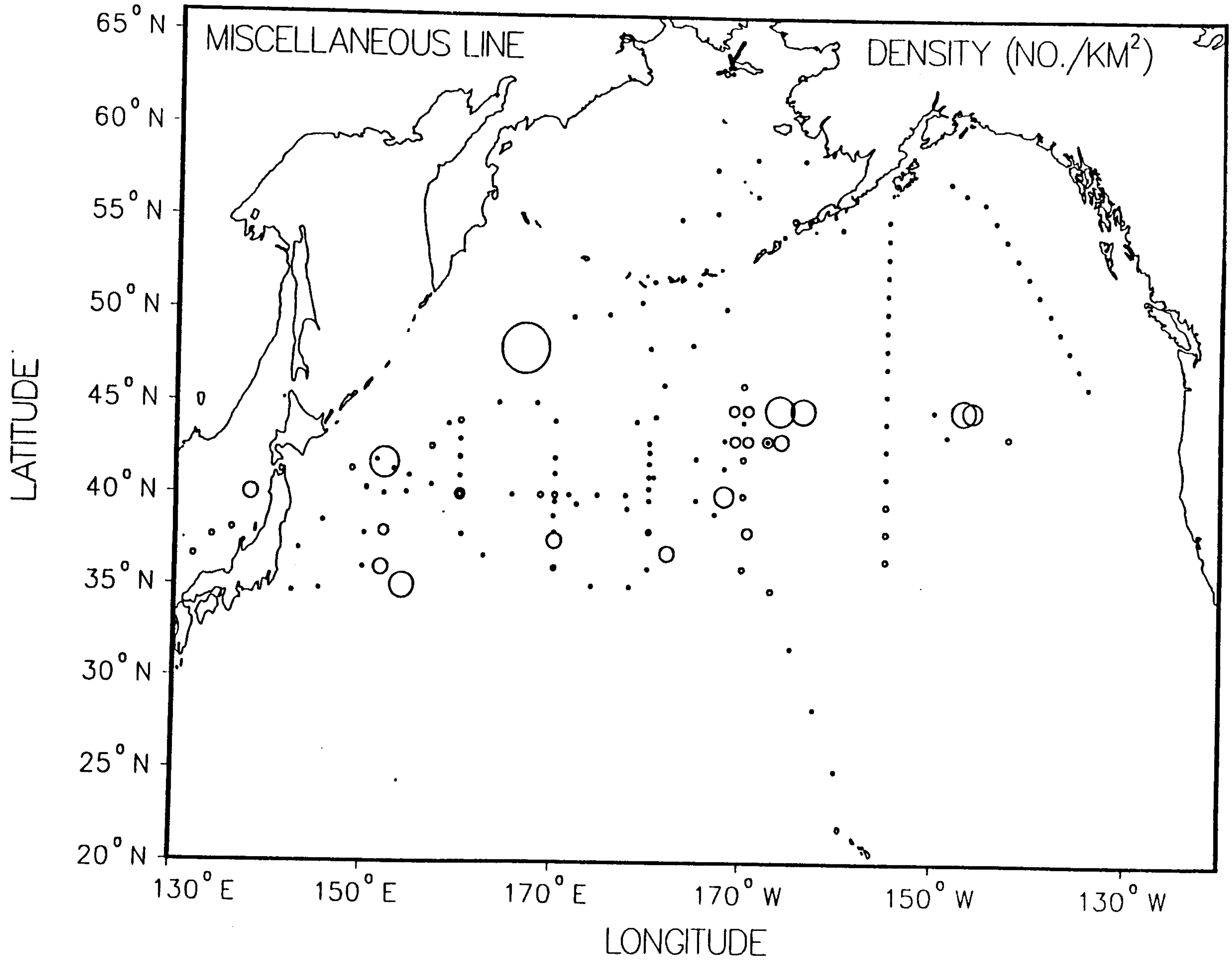

Figure 7.--Densities of miscellaneous lines/threads, 1985-88. Solid black circles indicate stations at which neuston plastic was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 40,500 pieces/km^2.

DISCUSSION

The distribution of neuston plastic results from two main phenomena, heterogeneous geographic input of plastic and subsequent redistribution by currents and winds. In addition, a phenomenon of unknown importance is the in situ decomposition of plastic in the ocean.

It appears that there is heterogeneous geographic input of neuston plastic, with much of it originating in the western Pacific. This conclusion is indicated by the high densities in and around the Japan Sea and nearshore Japan, where the highest densities of both neuston plastic and marine debris (Day et al. 1990) were recorded. The most polluted water in this area were Tokyo Bay (which had far more plastic than Day has ever seen elsewhere in the Pacific--he was unable to sample there) and localized areas in the Japan Sea. At the other extreme was the poorly populated Bering Sea area, where low rates of input probably occur. The low human population around much of the Gulf of Alaska probably contributes to the low densities there, also.

After entering the ocean, however, neuston plastic is redistributed by currents and winds. For example, plastic entering the ocean in Japan is moved eastward by the Subarctic Current (in Subarctic Water) and the Kuroshio (in Transitional Water, Kawai 1972; Favorite et al. 1976; Nagata et al. 1986). In this way, the plastic is transported from high-density areas to low-density areas. In addition to this eastward movement, Ekman stress from winds tends to move surface waters from the subarctic and the subtropics toward the Transitional Water mass as a whole (see Roden 1970: fig. 5). Because of the convergent nature of this Ekman flow, densities tend to be high in Transitional Water. In addition, the generally convergent nature of water in the North Pacific Central Gyre (Masuzawa 1972) should result in high densities there also.

One point that is not entirely clear is the cause of the low densities of neuston plastic in Subarctic Water. Part of the reason for these low densities is the apparently low input from shipping in this area: densities of both neuston plastic and marine debris in this area are low, suggesting little input from ships. The role of the divergent Alaska Gyre in helping to maintain these low densities is unclear, however. For example, neuston plastic tends to concentrate near the edges of the subarctic water mass, with little occurring in its center (Fig. 1), as would be expected for an upwelling gyre. On the other hand, the rate of vertical advection (in the low hundreds of meters/year, with downwelling occurring much of the year; T. C. Royer, Institute of Marine Sciences, University of Alaska, Fairbanks, Alaska, pers. commun.) is much lower than the rate of lateral advection (ca. 3,000 km/year at a speed of 15 cm/sec; Favorite et al. 1976), which should result in upwelling having little effect on the distribution of neuston plastic in this gyre.

A third factor, and one of unknown importance, is the in situ decomposition of larger marine debris plastic into small neuston plastic. As discussed by Day and Shaw (1987), the small percentage of raw plastic pellets and the high correlation between abundances of debris plastic and neuston plastic suggested that in situ decomposition was occurring. Although the present study did not test this hypothesis, we believe that the in situ decomposition of plastic can be important. The large pool of debris plastic and neuston plastic (particularly fragments) in Transitional Water probably is resident for a long period of time and appears to be decomposing there. For example, our impression was that transparent neuston plastic in this area tended to be opaque on the surface, to have more surface crazing (Gregory 1978, 1983), and to be more brittle than did most from Subarctic Water, where it tended to be more transparent on the surface and more pliable. The same phenomenon was true for much of the marine debris plastic in Transitional Water, where it was heavily bleached and heavily encrusted, suggesting long residence time. In reality, however, chemical weathering (leaching of plasticizers from the plastic matrix, causing the remaining plastic to be brittle and more susceptible to mechanical weathering), thermal weathering (increasing the rate of chemical weathering), and solar weathering (from strong sunlight) probably are most important in the in situ production of fragments of neuston plastic in Transitional and Subtropical Waters, whereas mechanical weathering (from rough seas) probably is most important in stormier Subarctic Waters. Finally, thermal (i.e., freezing) and mechanical weathering probably are most important in the stormy, cool Bering Sea, which is ice-covered in winter.

Frequencies of colors of neuston plastic in the North Pacific differed from frequencies of colors of neuston plastic ingested by seabirds (Day et al. 1985). For example, white, yellow, tan, and brown neuston plastic (light colors) represented only 40.0% of total identified neuston plastic in the ocean, whereas it represented 85.0% of neuston plastic ingested by seabirds. One of the largest differences was in tan plastic, which composed only 2.6% of the identified neuston plastic in the ocean but 55.1% of the neuston plastic eaten by seabirds. The largest difference was in transparent plastic, which represented 44.9% of the identified neuston plastic in the ocean but was not found in seabirds. Transparent plastic is not eaten by birds, probably because of difficulty in seeing it at sea (Day et al. 1985).

Neuston plastic can enter food chains when it is mistaken for prey (Day et al. 1985), especially where it becomes concentrated near important, localized prey. For example, there appeared to be a relationship between high densities of neuston plastic and high densities of water-striders, *Halobates sericeus* (Insecta: Gerridae) in Transitional and Subtropical Waters. These marine insects live at the surface of the ocean and are eaten by at least nine species of tropical seabirds that breed in the Hawaiian Islands and feed in these water masses. Water-striders are especially important prey of blue-gray noddies, *Procelsterna cerulea*, Bulwer's petrels, *Bulweria bulwerii*, and Bonin petrels, *Pterodroma hypoleuca*, with the latter two species also containing significant amounts of neuston plastic (Harrison et al. 1983; Cheng et al. 1984). We suspect that these insects are moved slowly into microscale convergences at the same time that plastic and other organisms are. For example, the density of water-striders was 136,000/km^2 at one station where the density of neuston plastic was 113,300 pieces/km^2; the highest density of water-striders was ca. 250,000/km^2 (Day unpubl. data). Given the co-occurrence of water-striders and neuston plastic in some tropical seabirds, we suggest that many of these birds are feeding in these microscale convergences, where they are picking up water-striders, other plankters, and neuston plastic. Indeed, Day has seen surface-feeding planktivorous seabirds (phalaropes and storm-petrels) feeding in large numbers in microscale convergences in the Oyashio-Kuroshio Confluence. These convergences contained visible lines of kelp wrack, plastic, and other marine debris.

Another group that ingests neuston plastic as well as planktonic prey in coastal and oceanic microscale convergences is sea turtles (Carr 1987). Young turtles apparently feed in these convergences during the first year or more at sea, when they drift with the currents and hence act much like neuston plastic. (During this period they also may become entangled in marine debris plastic.) Later, as they become older, these turtles both ingest larger pieces of marine debris plastic and become entangled in marine debris plastic (Balazs 1985).

Microscale convergences may be found in many areas of the world ocean (e.g., Owen 1981; Bourne and Clark 1984), and they may occur in areas different from the general areas of concentration discussed above. From our experience, microscale convergences concentrating neuston plastic are near lat. 28°-29°N north of Hawaii; in and near the Subarctic Front as microscale ephemeral convergences; in the complex Oyashio-Kuroshio Confluence east of Japan (including the ephemeral, mobile warm-core and cold-core rings; Nagata et al. 1986); at scattered locations in the Japan Sea; and probably in and around the Subtropical Front (i.e., around lat. 30°-32°N).

Perhaps the most impressive microscale convergences are in and around the Subarctic Front. Here, dynamic instabilities in surface layers (Roden 1970) create numerous ephemeral convergences in the zone lat. 37°-42°N and in the Oyashio-Kuroshio Confluence east of Japan. This juxtaposition of high biological productivity, physical complexity, large numbers of seabirds that ingest neuston plastic, and large amounts of neuston plastic increases the possibility of ingestion of that plastic.

ACKNOWLEDGMENTS

Most of the work was done while Day was an Angus Gavin Memorial Fellow, a Sea Grant Fellow, or a Resources Fellow at the University of Alaska. Additional funding came from the National Marine Fisheries Service (NMFS), NOAA (contracts 40ABNF63228 and 43ABNF702983) and two contracts from the Joint Institute for Marine and Atmospheric Research at the University of Hawaii. Additional samples were collected by James Seger and Richard Rowlett of NMFS and by Amy Stone of the U.S. Fish and Wildlife Service (FWS). Samples were collected aboard the TV *Oshoro Maru* of Hokkaido University, Hakodate, Japan; RV *Pusan 851* of the National Fisheries Research and Development Agency, Government of the Republic of Korea, Pusan, Korea; RV *Miller Freeman* of the Northwest and Alaska Fisheries Center, NMFS, Seattle, Washington, RV *Eagle* of the FWS, Homer, Alaska; and RV *Alpha Helix* of the Institute of Marine Sciences, University of Alaska, Fairbanks, Alaska. We thank the captains, officers, and crews of these ships for assistance in collecting the samples. This manuscript was improved by comments from three anonymous reviewers. This is Contribution No. 827 of the Institute of Marine Sciences, University of Alaska, Fairbanks, AK 99775.

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