THE QUANTITATIVE DISTRIBUTION AND CHARACTERISTICS OF MARINE DEBRIS IN THE NORTH PACIFIC OCEAN, 1984-88

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ABSTRACT

The distribution, abundance, and characteristics of marine debris in the North Pacific, Bering Sea, and Japan Sea were studied during the 5-year period 1984-88 using standardized observations at 181 daily transect stations encompassing approximately 21,420 km of observations, for a total of 1,070 km^2 of sampling. The most abundant debris type was plastic, which composed 89.3% of the total 2,127 debris items seen on transect; other debris items consisted of glass (3.3%), wood (3.2%), paper/fiber (2.4%), metal (0.5%), rubber (0.2%), and unidentified debris objects (1.0%). The most abundant plastic type was fragments (34.2%); other main plastic types were Styrofoam objects (22.5%), sheets and bags (18.2%), gillnet floats (5.0%), polypropylene line (3.1%), miscellaneous floats (2.8%), and miscellaneous/unidentified plastic objects (12.3%). Gillnet fragments, trawl net fragments, unidentified net fragments, and uncut plastic strapping, which were minor components of the plastic debris, were recorded a total of 46 times, primarily between lat. 37° and 44°N, in and near the Subarctic Front. The distribution and characteristics of the 6 general debris types are presented, as well as the distribution and characteristics of the 11 main plastic types. The highest densities of marine debris generally occurred in Japan Sea and nearshore Japan Water, Transitional Water, and Subtropical Water. Densities of most types of marine debris generally were low in Subarctic Water and Bering Sea Water. Heterogeneous geographic input, currents, and winds are important in locally concentrating marine debris.

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.

Appendix Table 11.--Final disposition of vessel-generated garbage before and after MARPOL Annex V (annual quantities) (MT = metric tons). Summary table.

Sector	Total MT generated	Before MARPOL Annex V						After MARPOL Annex V[a]							
		Off-loaded in port		Incinerated at sea		Dumped overboard		Off-loaded in port				Incinerated at sea		Dumped overboard	
								Plastics		Other					
		MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3	MT	m^3
Merchant shipping	30,949	3,302	39,794	1,148	14,971	26,499	349,304	1,626	311,353	2,737	6,255	4,381	57,132	22,204	103,685
Commercial passenger ships	258,074	232,121	3,026,799	638	8,322	25,315	330,095	22,490	2,304,400	233,340	1,060,557	1,117	14,564	1,128	5,265
Commercial fishing	233,177	0	0	0	0	233,177	3,040,564	15,373	1,352,768	0	0	3,723	48,542	214,081	999,660
Recreational boating	636,055	424,036	5,529,325	0	0	212,018	2,764,662	39,848	4,975,109	554,892	2,771,045	0	0	41,315	128,964
Offshore oil and gas operations	16,710	10,733	139,958	0	0	5,977	18,656	398	49,740	5,547	72,799	0	0	0	0
Miscellaneous vessels	1,637	5	60	0	0	1,633	20,778	109	5,372	0	0	306	3,986	1,223	5,709
U.S. Navy	57,596	0	0	0	0	57,596	751,040	3,859	2,409,124	0	0	0	0	53,737	250,929
U.S. Coast Guard	4,317	1,452	28,786	0	0	2,864	8,941	289	126,913	765	2,604	0	0	3,262	10,183
U.S. Army	490	0	0	0	0	490	6,388	33	9,143	0	0	0	0	199	621
National Oceanic and Atmospheric Administration research vessels	317	7	165	88	1,146	222	2,463	11	331	0	0	148	1,926	158	737
Total	1,239,322	671,656	8,764,887	1,874	24,439	565,791	7,292,892	84,037	11,544,253	797,282	3,913,261	9,674	126,150	337,306	1,505,752

[a]Assumes full compliance with Annex V requirements.

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INTRODUCTION

Marine debris, especially plastic debris, increasingly is recognized as a national and international pollution problem (Shomura and Yoshida 1985; Wolfe 1987). Debris presents problems on beaches, where it is aesthetically displeasing, is expensive (and probably impossible) to remove, causes unnecessary mortality of coastal wildlife, and (in the case of some medical, military, and industrial wastes) is potentially toxic. Debris also can cause problems at sea, where it can damage vessels, entangle marine animals, and result in the deaths of some animals that mistake it for food. Although the general nature of the marine debris problem is understood, the actual magnitude of the problem is unknown, because much of the information about it is anecdotal. For instance, we know that the northern fur seal, *Callorhinus ursinus*, become entangled and die in derelict fishing nets at sea, but estimates of the abundance of derelict nets at sea are highly uncertain (Pruter 1987). Consequently, estimates of both the true mortality rate of fur seals due to entanglement and the true effects of this mortality on fur seal populations also are uncertain (but see Fowler 1982, 1985, 1987).

During the last two decades, several workers have systematically observed floating debris and lost plastic nets in the North Pacific Ocean (Venrick et al. 1973; DeGange and Newby 1980; Dahlberg and Day 1985; Jones and Ferrero 1985; Yoshida and Baba 1985; Baba et al. 1986; Day and Shaw 1987; Mio and Takehama 1987; Yagi and Nomura 1987) and stranded debris on coastal beaches (Merrell 1980, 1984). These studies have shown that marine debris is distributed widely, is of several types, and is distributed by surface currents and winds.

The objective of this study was to improve our knowledge of the quantitative distribution and characteristics of marine debris in the North Pacific Ocean. Specifically, we wanted to: (1) describe the quantitative distributions of the six main types of marine debris; (2) describe the comparative at-sea densities of the main debris types; (3) describe the mean dimensions of the main debris types; (4) describe the quantitative distributions of the 11 main types of plastic debris; (5) describe the frequencies of colors of the main plastic types; and (6) examine the effects of input, currents, and winds on the quantitative distribution of marine debris. Because of the extensive geographic coverage of the work, this study constitutes the first complete analysis and the most detailed synoptic picture of marine debris anywhere in the world ocean.

METHODS

We collected data on the density (number per square kilometer), types, sizes, and colors of marine debris at 181 debris transect stations in the Bering and Japan Seas and the North Pacific Ocean north of Hawaii. At each station, we counted, identified, and estimated the two largest dimensions (at least 2.5 × 2.5 cm) of marine debris within 50 m of one side of a ship moving forward at a known rate of speed for a known period of time (Dahlberg and Day 1985; Day and Shaw 1987). The only types of debris that were sampled as far as we could see from either side of a moving ship were

gillnet fragments, trawl net fragments, unidentified net fragments, and uncut pieces of plastic strapping. This paper includes some published data from 38 stations in 1984 (Dahlberg and Day 1985) and 49 stations in 1985 (Day and Shaw 1987); the data from the other 94 stations are from 1986 to 1988 and have been combined with the 1984-85 data for a broader overview of patterns in the North Pacific.

The sampling surveyed approximately 21,425 km of ocean, for a total of approximately 1,073 km^2 of sampling (Fig. 1). The total effort consisted of 854 h 47 min (854:47) of sampling at 152 of the stations during which observation conditions were recorded. Effort by observation condition was: poor 21:50 (2.6% of the total effort of known conditions); fair 163:30 (19.1%); moderate 253:00 (29.6%); good 320:17 (37.5%); and very good 96:10 (11.3%). We decreased sampling effort when conditions were less than moderate (21.7% of total effort during known conditions) and sampled extensively when conditions were moderate to very good (78% of total effort during known conditions). Sampling was not conducted during periods when high waves could affect sightability of debris.

General debris types were standardized and consisted of glass, metal, paper/fiber, plastic, rubber, wood, or miscellaneous/unidentified debris. Plastic debris types also were standardized: fragment, Styrofoam (which may include foamed plastics of other chemical composition), polypropylene line fragment (which may include synthetic lines of other chemical composition), gillnet float, miscellaneous float, gillnet fragment, trawl net fragment, unidentified net fragment, uncut plastic strapping, sheet/bag, and miscellaneous/unidentified plastic debris. The two largest dimensions of pieces of debris were estimated in centimeters. Pieces of plastic debris were identified to the same standardized colors that were used for neuston plastic (Day et al. 1990): black/gray, blue, brown, green, orange, red/pink, tan, transparent, white, yellow, and mixed/unidentified colors.

Data were compiled as the density (number/km^2) of total marine debris, of each general type of marine debris, and of each type of plastic debris at each station. We stratified the density data into five oceanographic water mass strata: Bering Sea Water, Subarctic Water (north of the Subarctic Front or north of approximately lat. 42°N), Subtropical Water (south of the Subtropical Front or south of approximately lat. 31°N), Japan Sea/nearshore Japan Water (west of approximately long. 150°E), and Transitional Water (Subarctic Front, Transition Zone, and Subtropical Front). We then subjected the stratified density data (total density, the 6 general debris types, and the 11 plastic debris types) to Kruskal-Wallis tests (Conover 1980; Zar 1984). For each data set, we tested the hypothesis:

H_0: The density does not vary among water masses.

When test results were significant, we conducted multiple comparison tests (Conover 1980) to determine which water masses were significantly different.

The size data were combined into 10-cm size classes for sizes up to 100 cm; larger debris items were combined into size classes 101-200 cm,

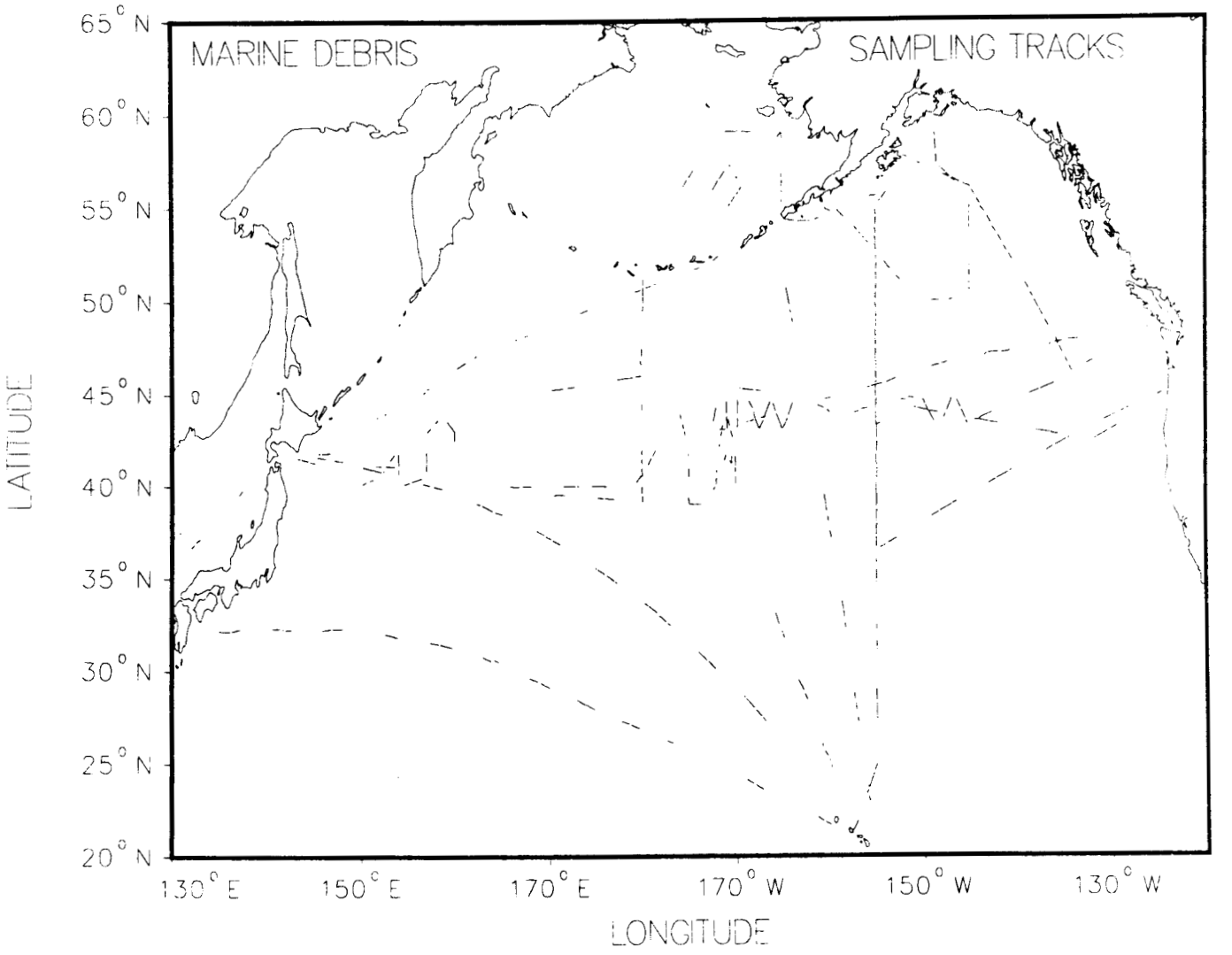

Figure 1.--Cruise tracks for marine debris sampling, 1984-88.

>200 cm, or unknown. The size data were compiled for each of the six general debris types but not for the individual plastic types. 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

Total Debris

We recorded 2,127 debris objects on the 181 debris transects. Plastic was the most common general type of debris, being recorded 1,899 times (89.3% of the total number of debris objects). Glass was next in frequency (72 objects; 3.3%), followed by 68 wood objects (3.2%), 53 paper/fiber

objects (2.4%), 10 metal objects (0.5%), and 4 rubber objects (0.2%). Miscellaneous/unidentified marine debris was recorded 22 times (1.0%).

Marine debris was widespread in occurrence, but occurred in greatest densities in the Japan Sea and off the eastern coast of Japan; it also was common along the Subarctic Front and in southern Transitional Water (Fig. 2). Lowest densities were in the central Alaska Gyre, in the Bering Sea, and in the vicinity of the Hawaiian Islands. The highest density of total marine debris was 36.7 pieces/km^2 at lat. 36°55'N, long. 132°30'E in the Japan Sea. Densities of total marine debris differed significantly among water masses ($H = 66.735$; $n = 181$; $df = 4$; $P < 0.05$; Table 1). Multiple comparisons indicated that densities were: Japan Sea/nearshore Japan Water = Transitional Water = Subtropical Water > Subarctic Water = Bering Sea Water.

Glass Debris

Glass objects were recorded 72 times. Glass containers of various types (miscellaneous bottle, sake bottle, jar, beer bottle, and Japanese whisky bottle, in decreasing order of frequency) were recorded 54 times (75.0% of total glass); bottles were the most abundant, being recorded 42 times (58%). The second main class of glass objects was light bulbs (11 objects; 15.3%), which were represented (in decreasing order) by incandescent bulbs, fluorescent bulbs, and floodlights. The remaining seven (9.7%) glass objects consisted of glass fishing floats (glass balls). The mean dimensions of glass debris were 17.9 × 33.7 cm ($n = 34$ objects of known dimensions).

Glass debris was widespread south of the Subarctic Water, occurring in greatest densities in southern Transitional Water, in the Japan Sea, and off eastern Japan; it was uncommon in Subarctic Water and absent in the Bering Sea (Fig. 3). The highest density was 1.3 pieces/km^2 at lat. 30°34'N, long. 173°10'W in Subtropical Water northwest of the Hawaiian Islands. Densities of glass differed significantly among water masses ($H = 34.744$; $n = 181$; $df = 4$; $P < 0.05$; Table 1). Multiple comparisons tests 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 > Subarctic Water, the two with the largest sample sizes (49 and 99, respectively). We suspect that other water masses were different but that sample sizes in most were too small for the multiple comparisons test to find significant differences. The pattern of mean ranks (in descending order) was: Japan Sea/nearshore Japan Water, Subtropical Water, Transitional Water, Subarctic Water, and Bering Sea Water.

Metal Debris

Metal objects were recorded 10 times. Metal cans of various sizes were the most common metal debris, being recorded eight times (80% of total metal). The remaining two metal objects were a 208.2 L (55-gal) drum and a metal trawl float (10% each). The mean dimensions of metal debris were 41.5 × 64.5 cm ($n = 5$ objects of known dimensions).

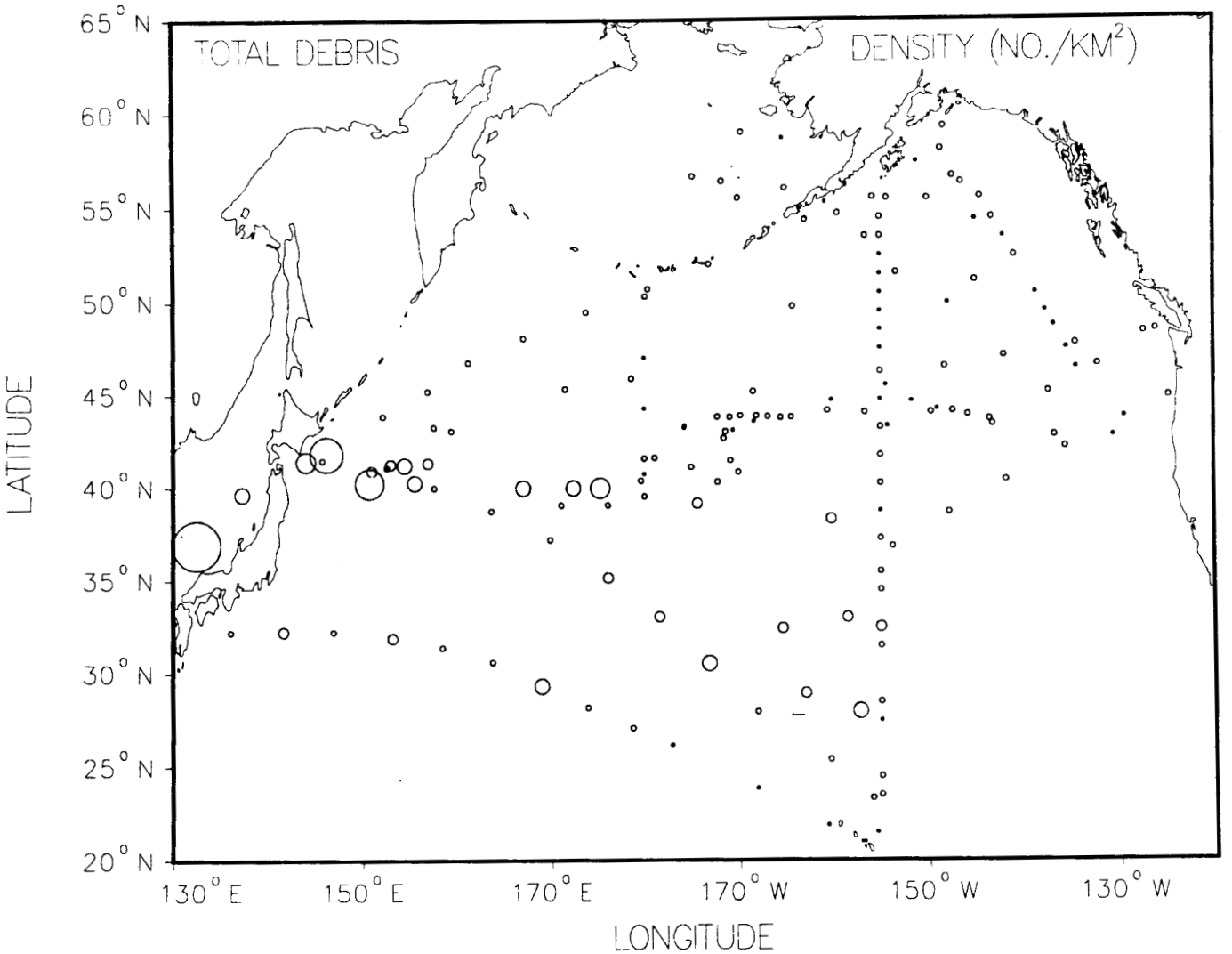

Figure 2.--Densities of total marine debris, 1984-88. Solid black circles indicate stations at which debris was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 36.7 pieces/km².

Metal debris was sporadic in occurrence and almost certainly originated from ships. The main areas of occurrence were the Japan Sea and off eastern Japan, with other records in the northern Gulf of Alaska and the eastern subarctic Pacific (Fig. 4). The highest density was 0.5 piece/km² at lat. 36°55'N, long. 132°30'E in the Japan Sea. Densities of metal debris appeared to differ significantly among water masses ($H = 10.106$; $n = 181$; $df = 4$; $P < 0.05$; Table 1). Multiple comparisons, however, indicated that none of the water masses were significantly different; we suspect that densities were too low overall for the multiple comparisons to find significant differences. The pattern of mean ranks (in descending order) was: Japan Sea/nearshore Japan Water, Transitional Water, Subarctic Water, and none in Subtropical and Bering Sea Waters.

Table 1.--Densities (number/km^2) of general types of marine debris in five water masses of the North Pacific, 1984-88.

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
n	7		99		49		18		8	
Distance sampled (km)	872.6		11,010.5		6,072.0		2,408.0		1,061.9	
Area sampled (km^2)	43.7		551.7		303.6		120.4		53.1	
Total density	0.3	0.3	0.4	0.6	3.6	3.8	2.4	3.5	11.5	12.8
Glass	0.0	0.0	<0.1	0.1	0.1	0.2	0.2	0.3	0.2	0.2
Metal	0.0	0.0	<0.1	<0.1	<0.1	<0.1	0.0	0.0	0.1	0.2
Paper/fiber	<0.1	0.1	<0.1	0.1	0.1	0.2	<0.1	0.1	0.1	0.8
Plastic	0.2	0.2	0.3	0.4	3.3	3.7	2.1	3.1	10.5	11.7
Rubber	0.0	0.0	0.0	0.0	<0.1	<0.1	0.0	0.0	0.1	0.1
Wood	<0.1	<0.1	0.1	0.3	<0.1	0.1	<0.1	0.1	0.2	0.2
Miscellaneous/ unidentified	<0.1	0.1	<0.1	<0.1	0.1	0.1	<0.1	0.1	0.0	0.0

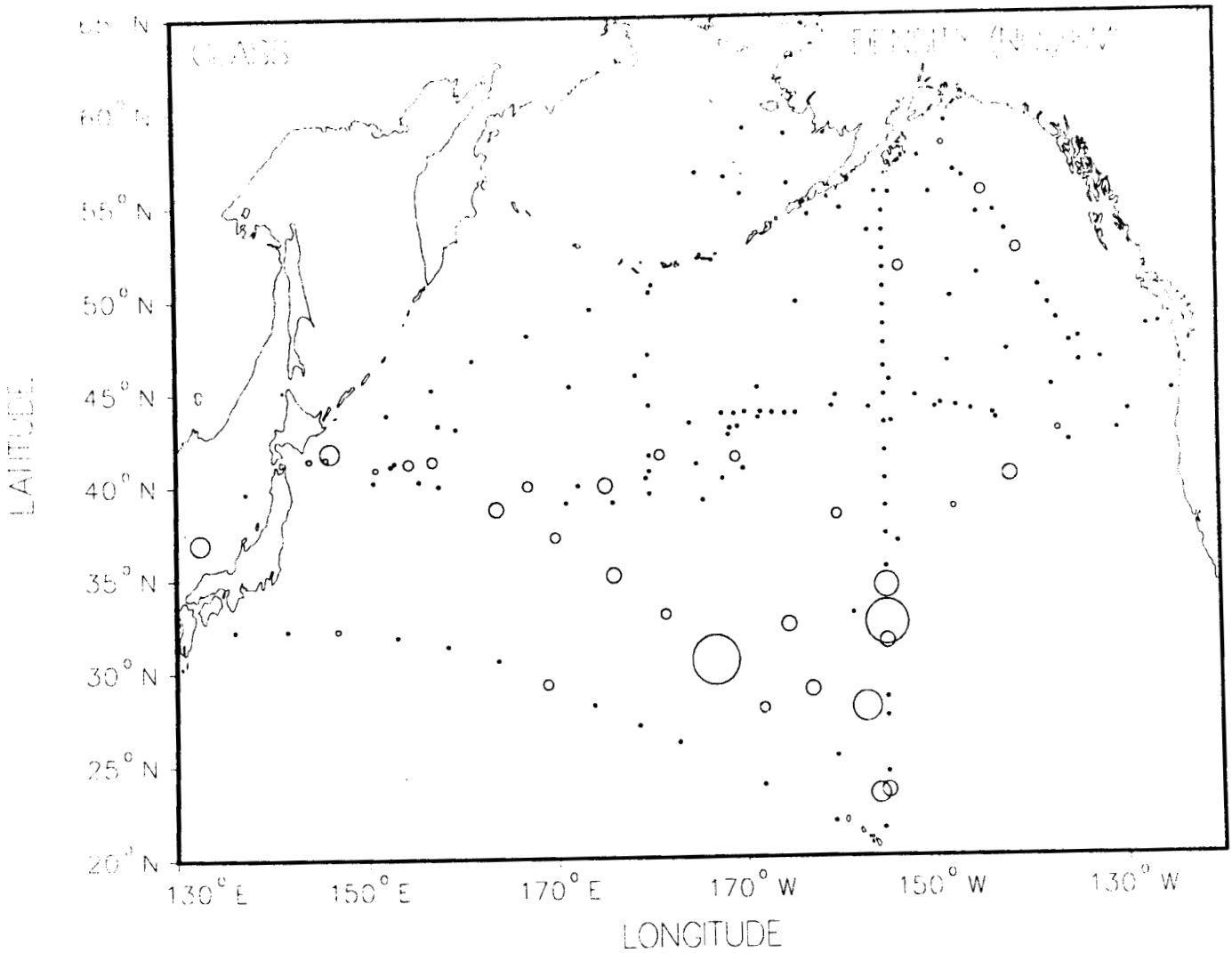

Figure 3.--Densities of glass debris, 1984-88. Solid black circles indicate stations at which glass debris was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 1.3 pieces/km^2.

Paper/Fiber Debris

Paper/fiber objects were recorded 53 times. Paperlike objects were the most common, being recorded 34 times (66.0% of total paper/fiber); of these, cardboard (fragments, boxes, sheets, and tubes) was recorded 19 times (35.8%), and paper (fragments, towels, cups, magazines, and cigarette packs) was recorded 16 times (30.2%). Hemp line was recorded 11 times (20.8%); it consisted of fragments of hemp deck lines from ships and of 1

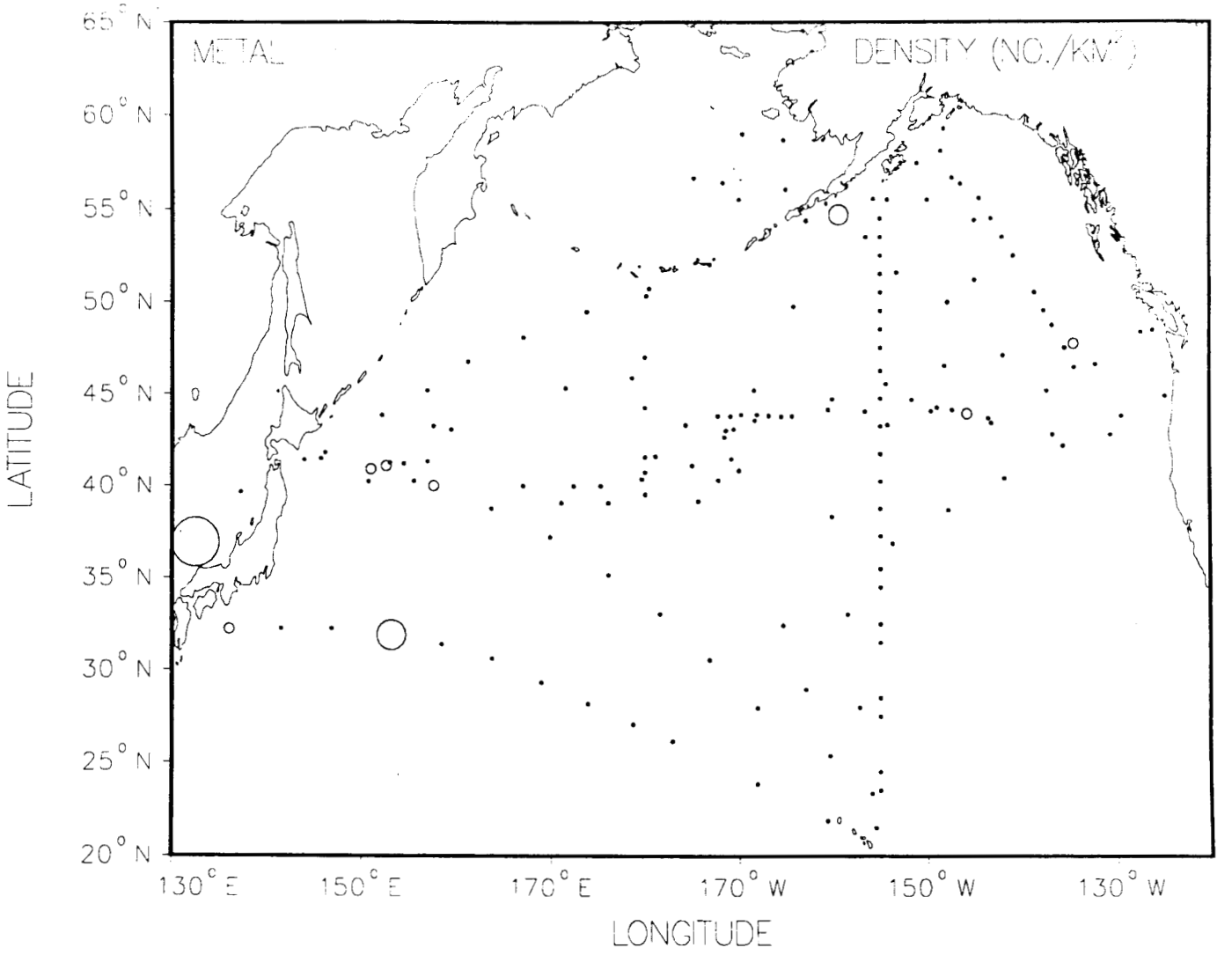

Figure 4.--Densities of metal debris, 1984-88. Solid black circles indicate stations at which metal debris was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 0.5 piece/km^2.

piece of twine. Woven debris was the least common kind of paper/fiber, being recorded seven times (13.2%); this category included cloth fragments and bags, canvas fragments and bags, and one carpet fragment. The mean dimensions of paper/fiber objects were 23.1 × 75.6 cm (n = 42 objects of known dimensions); the mean dimensions excluding objects >200 cm long were only 23.1 × 50.6 cm (n = 42 and n = 39, respectively), however.

Because paper decomposes rapidly at sea, paper/fiber debris occurred primarily near shore (e.g., the Japan Sea, off eastern Japan, the Bering

Sea) or in areas that are fished heavily (e.g., southeastern Bering Sea, flying squid fishery near the Subarctic Front east of Japan), where numerous fishing boats provide constant input of paper debris; most of the records of this debris type in southern Transitional Water and northern Subtropical Water are of hemp deck lines (Fig. 5). The highest density was 2.3 pieces/km^2 at lat. 36°55'N, long. 132°30'E in the Japan Sea. Densities of paper/fiber differed significantly among water masses ($H = 38.676$; $n = 181$; $df = 4$; $P < 0.05$; Table 1). Multiple comparisons indicated that densities were: Japan Sea/nearshore Japan Water > Transitional Water = Subtropical Water = Subarctic Water = Bering Sea Water.

Rubber Debris

Rubber objects were recorded only four times, the least of all general debris types. All four (100%) objects were rubber gloves, which frequently are used on fishing boats. The mean dimensions of rubber objects were 15.5 × 25.5 cm ($n = 3$ objects of known dimensions).

Rubber debris was recorded at only three stations: at lat. 32°15'N, long. 141°36'E in Transitional Water east of Japan; at lat. 36°55'N, long. 132°30'E in the Japan Sea; and at lat. 27°59'N, long. 157°13'W in Subtropical Water north of the Hawaiian Islands. The highest density was 0.3 piece/km^2 in the Japan Sea. Densities of rubber appeared to differ significantly among water masses ($H = 28.715$; $n = 181$; $df = 4$; $P < 0.05$; Table 1). Multiple comparisons, however, found no significant differences; we suspect that densities were too low overall for the multiple comparisons to find differences. The pattern of mean ranks (in descending order) was: Japan Sea/nearshore Japan Water, Transitional Water, and none in Subtropical, Subarctic, and Bering Sea Waters.

Wood Debris

Wood objects were recorded 68 times. Sawed or milled wood objects were the most common (63 objects; 92.6% of total wood); this category consisted (in decreasing order of frequency) of boards, sawed logs (for shipping to sawmills), dock pilings, and large timbers or blocks that frequently are used as dunnage on ships. Bamboo objects (3; 4.4%) were next in abundance and consisted of flagpoles (for marking the ends of drift gillnets) and fragments. Finally, fabricated objects (2; 2.9%) were represented by one wooden pallet and what appeared to be a wooden ladder. The mean dimensions were 23.5 × 183.0 cm ($n = 62$ objects of known dimensions); the mean dimensions excluding objects >200 cm long were 23.5 × 78.8 cm ($n = 62$ and $n = 45$, respectively), however.

Wood debris occurred primarily near shore, probably because of its tendency to become waterlogged and sink with time. The highest densities were in the northern Gulf of Alaska, where harvested logs were common in the Alaska Coastal Current and farther offshore, in the Japan Sea and off the eastern shore of Japan; little wood debris was recorded far from shore, however (Fig. 6). The highest density was 2.8 pieces/km^2 at lat. 59°47'N, long. 148°17'W near the coast of the northern Gulf of Alaska. Densities of wood differed significantly among water masses ($H = 19.830$; $n = 181$; $df = 4$; $P < 0.05$; Table 1). Multiple comparisons indicated that densities

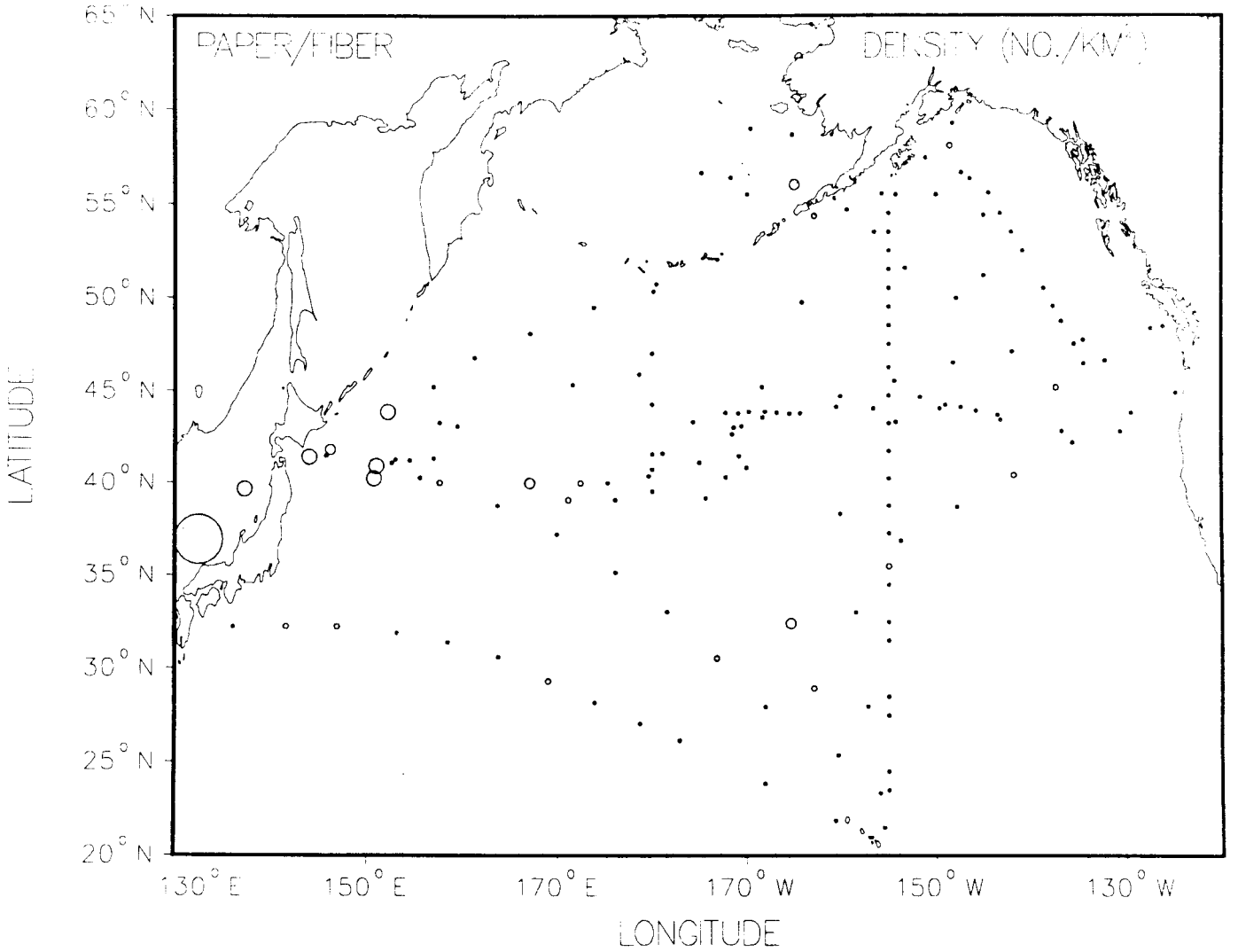

Figure 5.--Densities of paper/fiber debris, 1984-88. Solid black circles indicate stations at which paper/fiber debris was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 2.3 pieces/km^2.

were: Japan Sea/nearshore Japan Water > Subarctic Water = Subtropical Water = Transitional Water = Bering Sea Water.

Plastic Debris

Types of Plastic Debris

Of the 1,899 plastic debris objects recorded on transect, fragments were the most common type (649 objects). Styrofoam was next in abundance

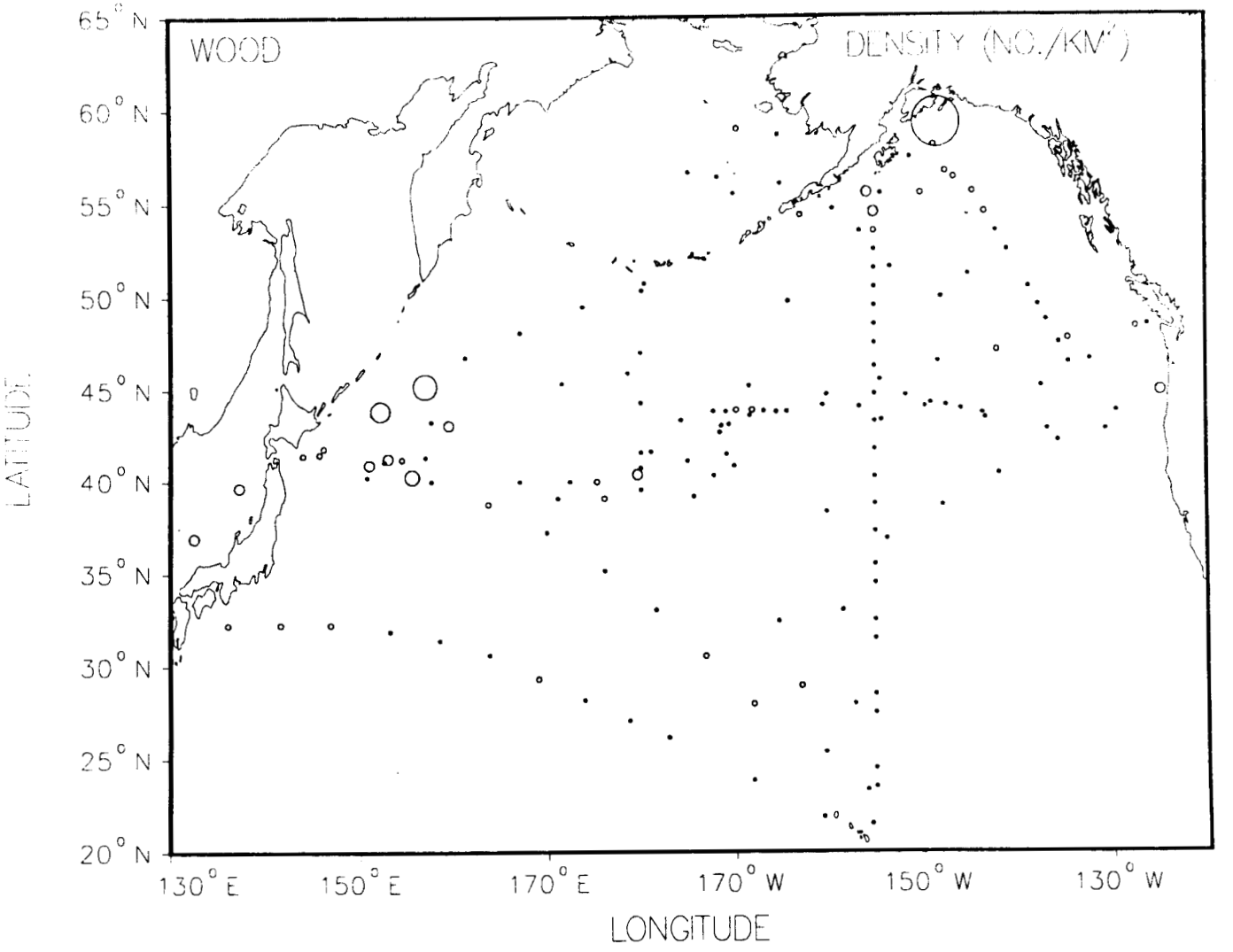

Figure 6.--Densities of wood debris, 1984-88. Solid black circles indicate stations at which wood debris was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 2.8 pieces/km².

(428 objects), followed by 346 sheets/bags, 95 gillnet floats, 59 polypropylene line fragments, 54 miscellaneous floats, 12 gillnet fragments (plus 8 seen off transect), 11 trawl net fragments (plus 3 seen off transect), 8 uncut plastic straps, and 3 unidentified net fragments (plus 1 seen off transect). Miscellaneous/unidentified plastic debris was recorded 234 times. The mean dimensions of plastic objects were 13.3 × 24.3 cm (n = 1,569 objects of known dimensions); the mean dimensions excluding objects >200 cm were 11.7 × 19.1 cm (n = 1,564 and n = 1,557, respectively).

As might be expected from its abundance overall, plastic debris was the most widespread of all debris types (Fig. 7). The highest densities were in the Japan Sea and off the eastern coast of Japan, with lower densities in the Subarctic Front east of Japan and in southern Transitional Water; the lowest densities were near the Hawaiian Islands, in Subarctic Water (especially in the Alaska Gyre), and in the Bering Sea. The highest density of total plastic debris was 32.6 pieces/km^2 at lat. 36°55'N, long. 132°30'E in the Japan Sea; local densities here were so high that Day was unable to census all marine debris, so he stopped sampling here. The only other high densities of plastic debris were 23.8 pieces/km^2 at lat. 41°50'N, long. 146°12'E and 18.2 pieces/km^2 at lat. 40°15'N, long. 150°46'E, both off the eastern coast of Japan. Densities of plastic differed significantly among water masses ($H = 74.168$; $n = 181$; $df = 4$; $P < 0.05$; Table 1). Multiple comparisons indicated that densities were: Japan Sea/nearshore Japan Water = Subtropical Water = Transitional Water > Subarctic Water = Bering Sea Water.

Fragments were irregular pieces of plastic (other than the specific categories discussed here) that apparently had been broken from other, larger pieces. They were the most abundant plastic type, being recorded 649 times (34.2% of total plastic). Fragments occurred in highest densities off eastern Japan and in the Japan Sea, with lower densities in northern Subtropical Water near the Subtropical Front; in contrast, they were uncommon in Subarctic Water and the Bering Sea (Fig. 8). The highest density was 18.9 pieces/km^2 at lat. 41°50'N, long. 146°12'E off the eastern coast of Japan. The density of plastic fragments differed significantly among water masses ($H = 62.887$; $n = 181$; $df = 4$; $P < 0.05$; Table 2). Multiple comparisons indicated that densities were: Japan Sea/nearshore Japan Water = Transitional Water > Subtropical Water = Subarctic Water = Bering Sea Water.

Styrofoam included all objects made of foamed polystyrene, including fragments, sheets, boxes or other containers, and fishing floats; based on observed colors and textures, we believe that none of this debris consisted of other types of foamed plastics (e.g., polyurethane). Styrofoam objects were recorded 428 times (22.5% of total plastic), making them second in abundance of all plastic types. As was seen for neuston plastic (Day et al. 1990), Styrofoam debris also is a "nearshore Japan/transitional species," with few records in Subarctic Water or the Bering Sea (Fig. 9). The highest density was 4.9 pieces/km^2 at lat. 36°55'N, long. 132°30'E in the Japan Sea. The density of Styrofoam differed significantly among water masses ($H = 58.655$; $n = 181$; $df = 4$; $P < 0.05$; Table 2). Multiple comparisons indicated that densities were: Japan Sea/nearshore Japan Water = Transitional Water = Subtropical Water > Subarctic Water = Bering Sea Water.

Polypropylene line is used more commonly than are other synthetic lines and largely has replaced hemp line on ships; consequently, we categorized all lines that appeared to be synthetic as polypropylene. Debris of this type consisted of intact lines and line fragments. Polypropylene lines were recorded 59 times (3.1% of total plastic). These lines were absent in the Bering Sea, were recorded in Subarctic Water only three times, and peaked in abundance in and around the Subarctic Front, in

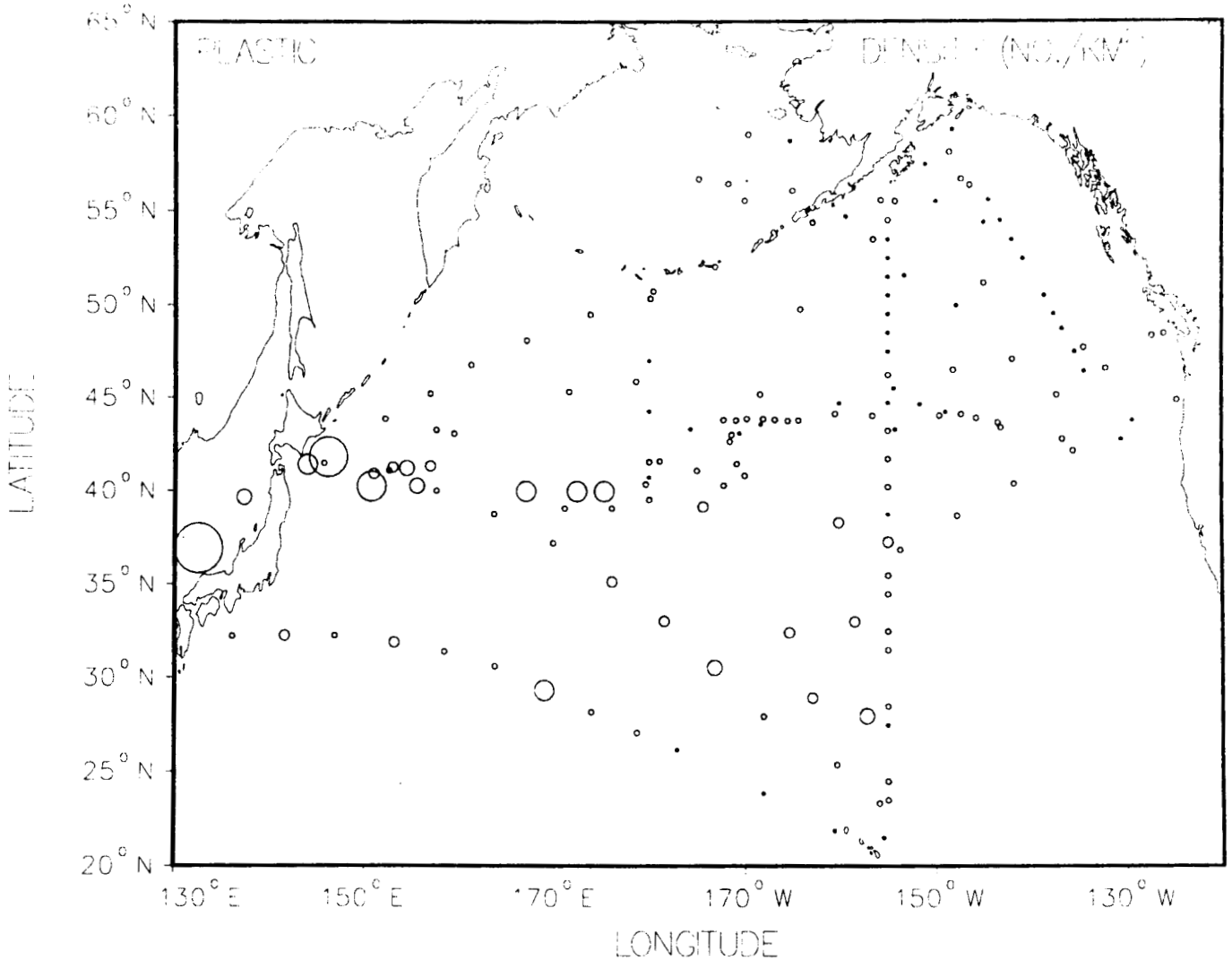

Figure 7.--Densities of plastic debris, 1984-88. Solid black circles indicate stations at which plastic debris was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 32.6 pieces/km².

the Japan Sea, and in and near the Subtropical Front (Fig. 10). The highest density was 1.2 pieces/km² at lat. 40°00'N, long. 175°17'E near the Subarctic Front in the central Pacific. Densities of polypropylene line differed significantly among water masses ($H = 27.068$; $n = 181$; $df = 4$; $P < 0.05$; Table 2). 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 > Subarctic Water, the two

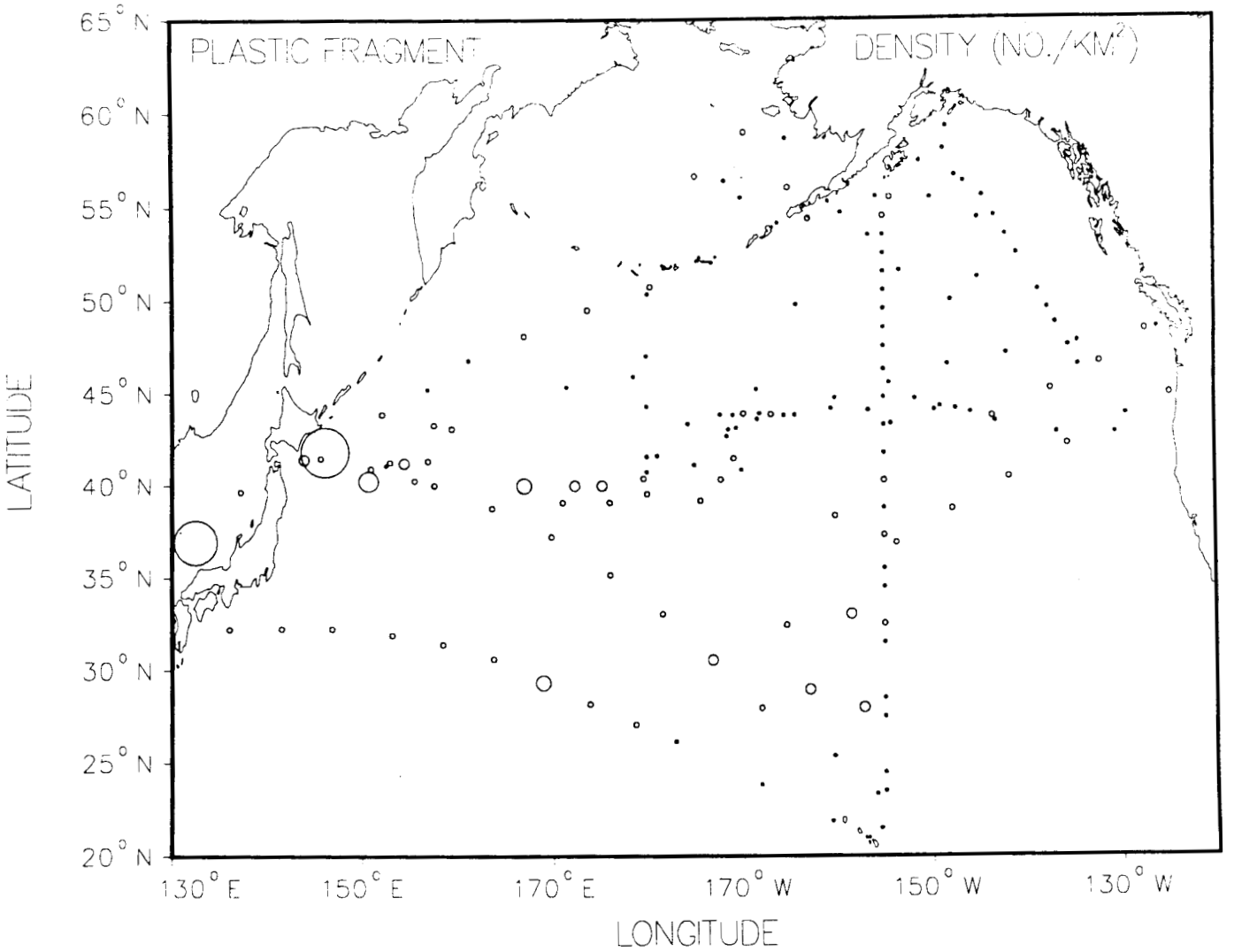

Figure 8.--Densities of plastic fragments, 1984-88. Solid black circles indicate stations at which plastic fragments was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 18.9 pieces/km^2.

with the largest sample sizes (49 and 99, 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: Transitional Water, Subtropical Water, Japan Sea/nearshore Japan Water, Subarctic Water, and Bering Sea Water.

Table 2.--Densities (number/km^2) of types of plastic debris 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
n	7		99		49		18		8	
Fragment	0.1	0.1	0.1	0.2	0.9	1.3	0.8	1.4	5.3	7.6
Styrofoam	<0.1	0.1	0.1	0.1	0.7	0.8	0.4	0.8	2.1	1.7
Polypropylene line	0.0	0.0	<0.1	<0.1	0.1	0.2	0.1	0.2	0.2	0.4
Gillnet float	0.0	0.0	<0.1	0.1	0.2	0.2	0.2	0.3	0.1	0.1
Miscellaneous float	0.0	0.0	<0.1	<0.1	0.1	0.1	0.1	0.1	0.1	0.2
Gillnet fragment	0.0	0.0	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.0	0.0
Trawl net fragment	0.0	0.0	<0.1	<0.1	<0.1	0.1	0.1	<0.1	0.0	0.0
Unidentified net fragment	0.0	0.0	0.0	0.0	<0.1	<0.1	0.0	0.0	0.0	0.0
Uncut strapping	0.0	0.0	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	0.1
Sheet/bag	<0.1	<0.1	<0.1	0.1	0.8	1.3	0.1	0.2	2.1	2.8
Miscellaneous/ unidentified	0.1	0.1	<0.1	0.1	0.5	0.5	0.3	0.4	0.6	0.5

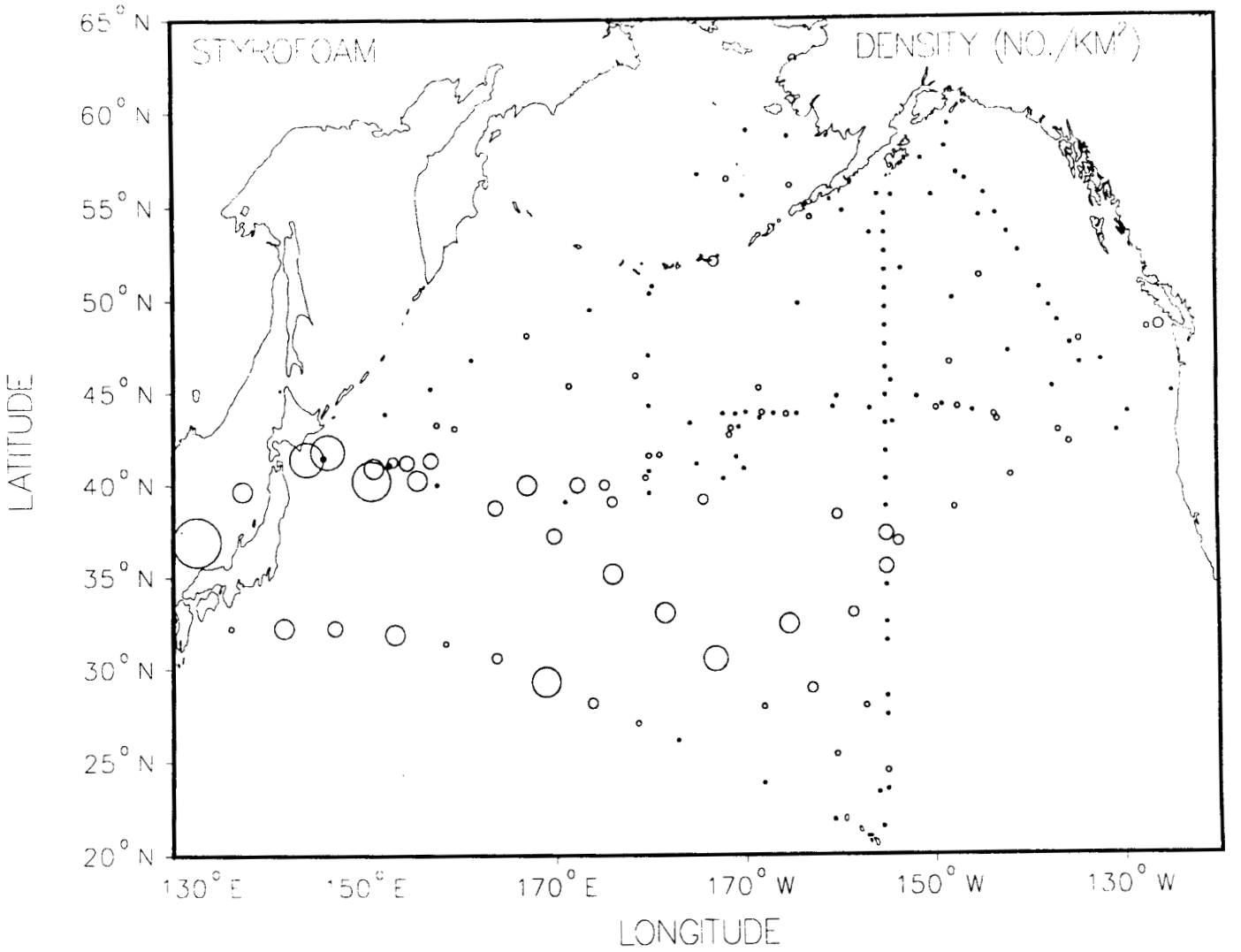

Figure 9.--Densities of Styrofoam, 1984-88. Solid black circles indicate stations at which Styrofoam was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 4.9 pieces/km^2.

Floats include gillnet floats, trawl net floats, longline floats, crab pot buoys, and large boat bumpers made out of plastic other than Styrofoam. They primarily represent various types of fishing floats.

Gillnet floats were widely distributed and were common, being recorded 95 times (5.0% of total plastic). They were especially common in and around the Subarctic Front (center of the major gillnet fishery for squid--see below), in southern Transitional Water, and in and near the Subtropical

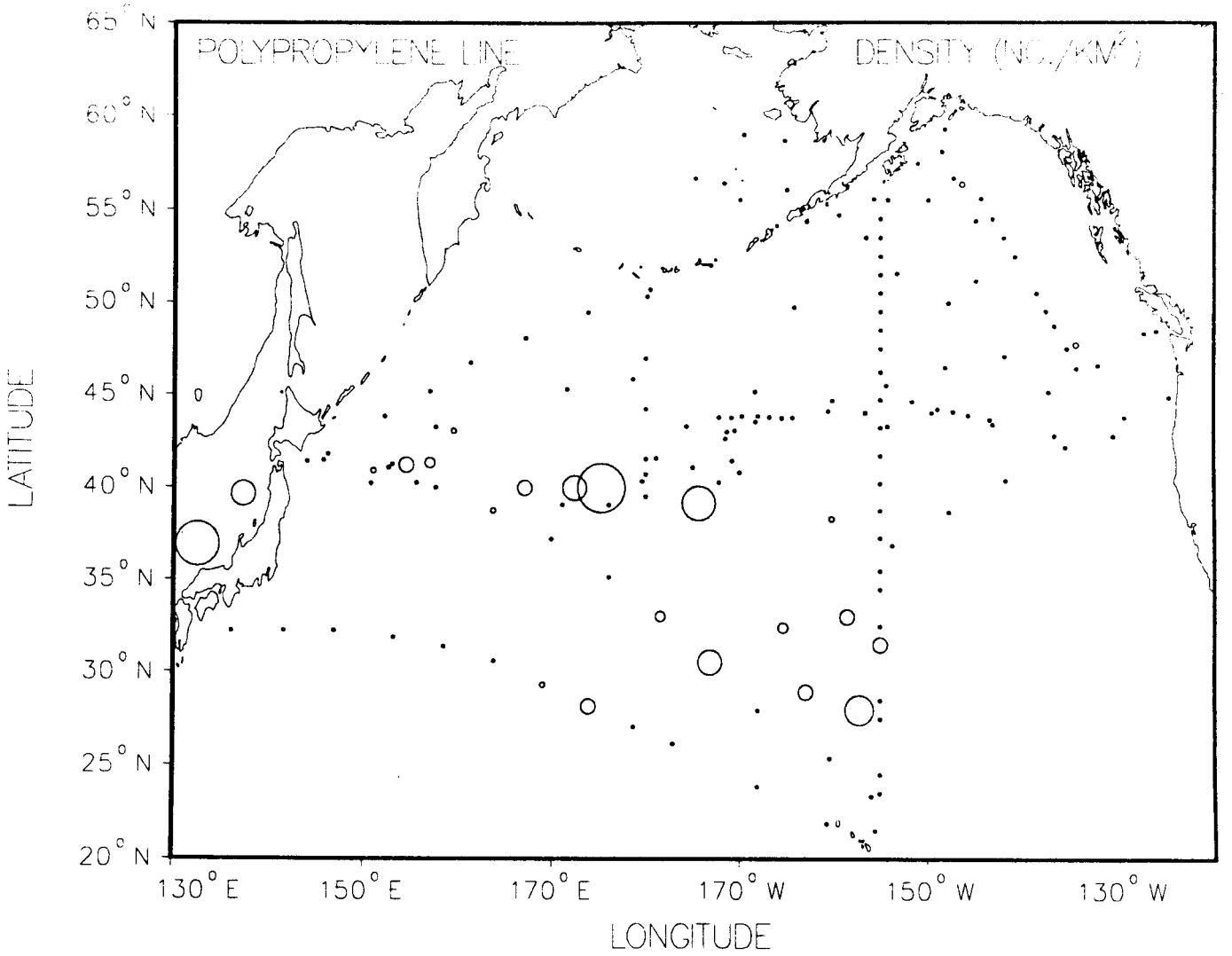

Figure 10.--Densities of polypropylene line, 1984-88. Solid black circles indicate stations at which polypropylene line was not recorded. Sizes of hollow circles indicate relative densities. The highest density was 1.2 pieces/km².

Front; the only place they were absent was in the Bering Sea, probably because of the limited sampling there (Fig. 11). The highest density was 0.8 piece/km² at lat. 40°15'N, long. 150°46'E near the Subarctic Front east of Japan and at lat. 27°59'N, long. 157°13'W in Subtropical Water north of Hawaii. Densities of gillnet floats differed significantly among water masses ($H = 28.690$; $n = 181$; $df = 4$; $P < 0.05$; Table 2). Multiple comparisons again were confusing, however, in that those water masses with the largest difference in mean ranks were not significantly different, whereas

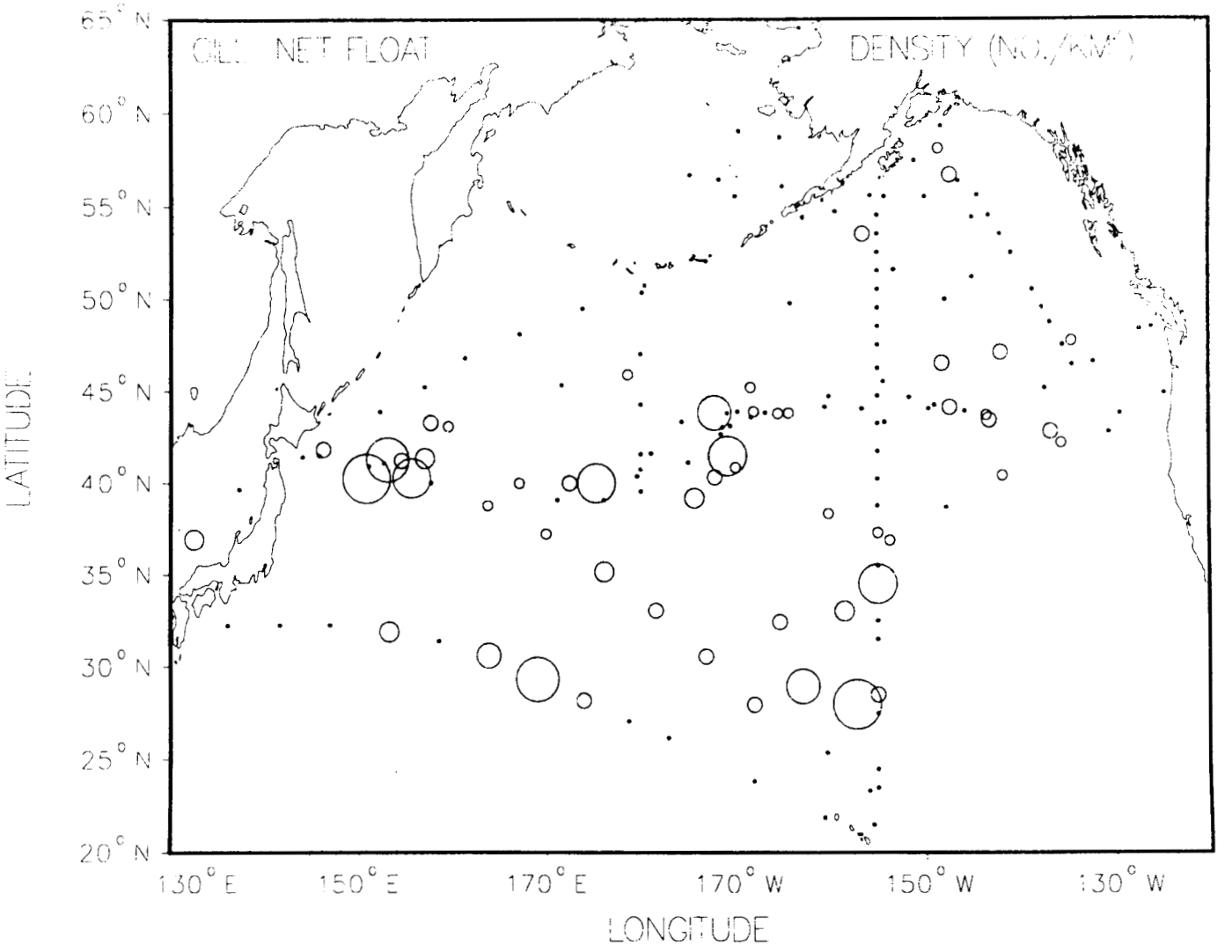

Figure 11.--Densities of plastic gillnet floats, 1984-88. Solid black circles indicate stations at which gillnet floats were not recorded. Sizes of hollow circles indicate relative densities. The highest density was 0.8 piece/km².

water masses with smaller differences in mean ranks were significantly different. The two water masses that were significantly different were Transitional Water > Subarctic Water, the two with the largest sample sizes (49 and 99, respectively). Again, 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: Transitional Water, Subtropical Water, Japan Sea/nearshore Japan Water, Subarctic Water, and Bering Sea Water.

Miscellaneous floats also were widespread at sea. These floats were concentrated in southern Transitional Water and Subtropical Water, with records scattered everywhere but the Bering Sea, again probably because of the limited sampling there (Fig. 12). These floats were rare in Subarctic Water as a whole, however. The highest density was 0.6 piece/km^2 at lat. 33°01'N, long. 158°31'W in Transitional Water north of Hawaii. Densities of miscellaneous floats differed significantly among water masses ($H = 29.842$; $n = 181$; $df = 4$; $P < 0.05$; Table 2). Multiple comparisons again were confusing, 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 Subtropical Water > Subarctic Water; one of these water masses had a moderate sample size and the other had a large sample size (18 and 99, respectively). We again 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, Subtropical Water, Transitional Water, Subarctic Water, and Bering Sea Water.

Although they were recorded only 34 times on transect and another 12 times off transect, net fragments and uncut packing straps are important components of marine debris, for they are thought to cause excessive mortality of some marine animals such as northern fur seals (Fowler 1982, 1985, 1987). These four plastic types were not distributed evenly in the North Pacific, but instead were concentrated between lat. 37° and 44°N (Fig. 13).

Gillnet fragments were recorded on transect 12 times and off transect 8 times; they were seen between lat. 25°37' and 45°15'N, with the most (3) seen at lat. 38°-39° and 42°-43°N (Fig. 13). The highest density was 0.7 piece/km^2 in Subtropical Water northwest of the Hawaiian Islands. Densities of gillnet fragments differed significantly among water masses ($H = 14.732$; $n = 181$; $df = 4$; $P < 0.05$; Table 2). Multiple comparisons, however, did not find significant differences. We suspect that densities were too low overall for the multiple comparisons to find significant differences. The pattern of mean ranks (in descending order) was: Subtropical Water, Transitional Water, Subarctic Water, and none in Japan Sea/nearshore Japan Water and Bering Sea Water.

Trawl net fragments were recorded on transect 11 times and off transect 3 times; they were seen between lat. 30°21' and 44°07'N, with the most (3) seen at lat. 40°-41° and 41-42°N (Fig. 13). The highest density was 0.2 piece/km^2, recorded at four stations near the Subarctic Front in the central and western North Pacific. Densities of trawl net fragments differed significantly among water masses ($H = 10.629$; $n = 181$; $df = 4$; $P < 0.05$; Table 2). Multiple comparisons did not find significant differences, however, and we suspect that densities were too low overall for the multiple comparisons to find significant differences. The pattern of mean ranks (in descending order) was: Transitional Water, Subtropical Water, Subarctic Water, and none in Japan Sea/nearshore Japan Water and Bering Sea Water.

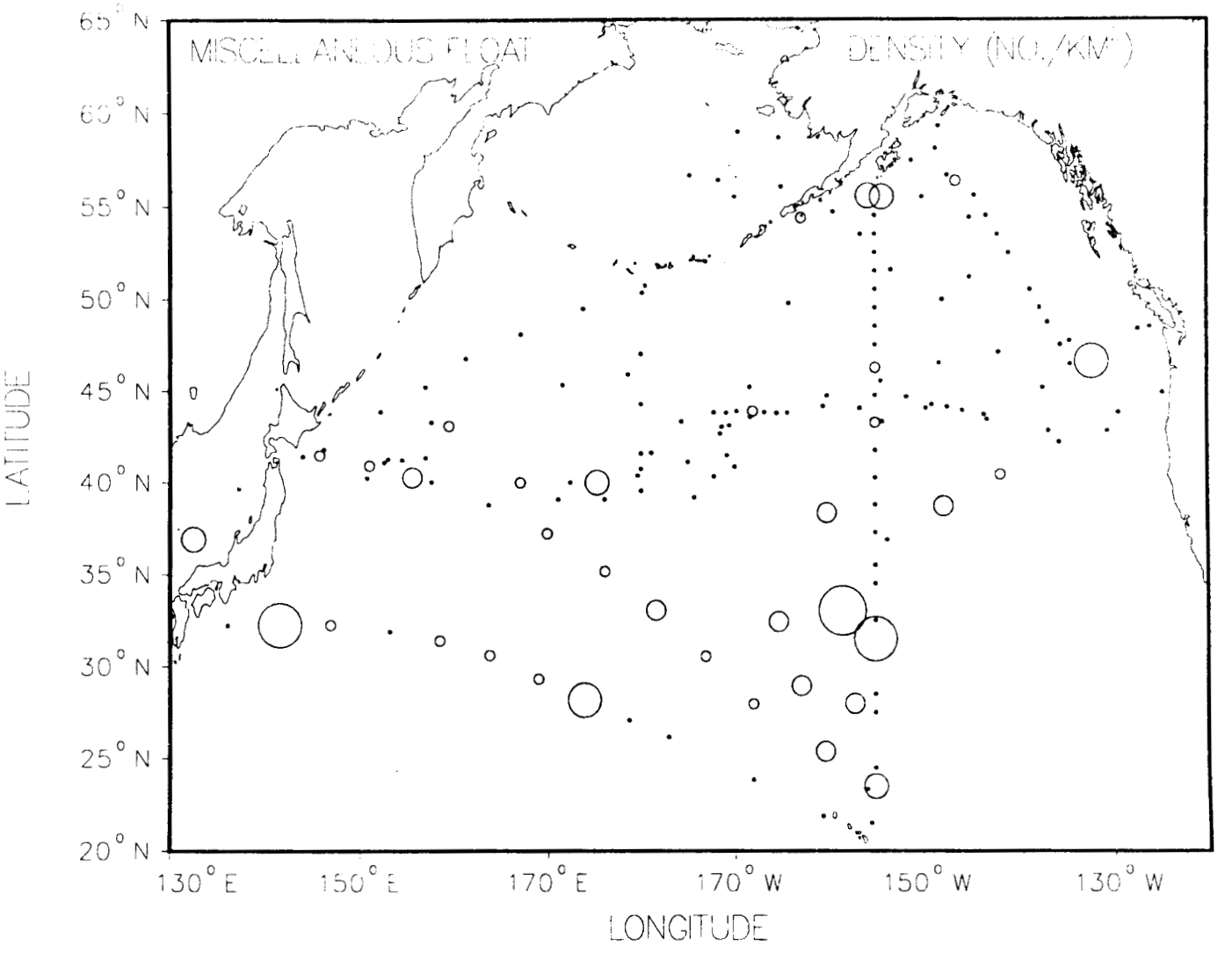

Figure 12.--Densities of miscellaneous plastic floats, 1984-88. Solid black circles indicate stations at which miscellaneous plastic floats were not recorded. Sizes of hollow circles indicate relative densities. The highest density was 0.6 piece/km^2.

Unidentified net fragments were recorded on transect three times and off transect once; they were seen between lat. 33°07′ and 43°35′N, with the most (two) seen at lat. 33°-34°N (Fig. 13). The estimated mesh size of these nets was 4 × 4 cm. The highest density was 0.3 piece/km^2 at lat. 33°01′N, long. 158°31′W in Transitional Water north of Hawaii. Densities of unidentified net fragments did not differ significantly among water masses ($H = 5.418$; $n = 181$; $df = 4$; $P > 0.05$; Table 2), probably because they were so low overall.

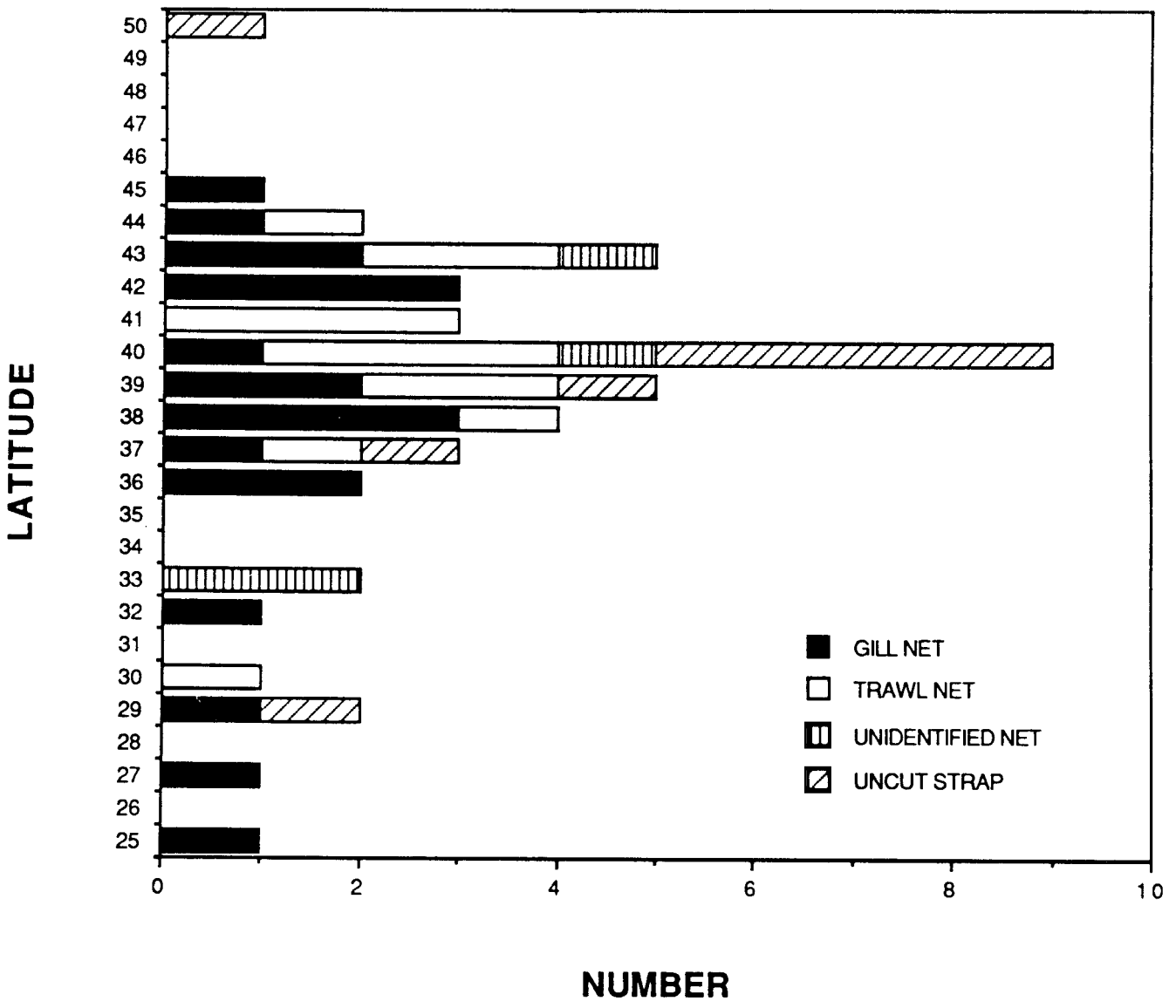

Figure 13.--Numbers of nets and uncut plastic strapping seen, by 1° blocks of latitude, 1984-88.

Uncut straps were recorded eight times, all on transect; they were seen between lat. 29°33′ and 50°03′N, with the most (four) seen at lat. 40°-41°N (Fig. 13). The highest density was 0.3 piece/km^2 at lat. 36°55′N, long. 132°30′E in the Japan Sea. Densities of uncut straps did not differ significantly among water masses ($H = 5.462$; $n = 181$; $df = 4$; $P > 0.05$; Table 2), probably because they were so low overall.

Sheets and bags, which are a pollution problem because they are eaten by and entangle sea turtles (Balazs 1985; Carr 1987), were recorded 346 times (18.2% of total plastic). Sheets and bags occurred in highest densities in the Japan Sea, off the eastern coast of Japan, and along the Subarctic Front east of Japan; this debris type was common in Transitional Water and was essentially absent from Subarctic Water and the Bering Sea (Fig. 14). The highest density was 7.9 pieces/km^2 at lat. 36°55′N, long. 132°30′E in the Japan Sea. Densities of sheets/bags differed significantly among water masses ($H = 61.202$; $n = 181$; $df = 4$; $P < 0.05$; Table 2). Multiple comparisons indicated that densities were: Japan Sea/nearshore Japan Water = Transitional Water > Subtropical Water = Subarctic Water = Bering Sea Water.

Miscellaneous/unidentified plastic consisted of both fabricated objects and truly unidentified pieces; the latter objects occurred when we encountered such high local densities that we were unable to record all details on individual plastic objects. One hundred fifty-seven containers of various kinds constituted 67.1% of this category and included bottles, jars, squeeze tubes, boxes, bowls, cups, pans, beer or soda cases, woven bags, and buckets. The remaining 77 objects were a diverse assortment of screens, sponges, lids, mats, bottle caps, sandals, trays, rings, shoe liners, shovels, pipes, toys, paddles, poles, baseball caps, handles, helmets, and unidentified plastic debris. The highest density was 1.3 pieces/km^2 at lat. 35°10′N, long. 176°01′E in Transitional Water in the central North Pacific, at lat. 40°15′N, long. 150°46′E near the Subarctic Front off eastern Japan, and at lat. 36°55′N, long. 132°30′E in the Japan Sea.

Colors of Plastic Debris

Plastic debris was recorded in all 10 of the standardized colors, plus miscellaneous/mixed colors (Fig. 15). White was by far the most common color, being recorded 922 times (48.6% of total plastic). The color tan was second in abundance (187; 9.9%), followed by transparent (124; 6.5%), blue (119; 6.3%), and yellow (86; 4.5%). The colors green (35; 1.8%), brown (32; 1.7%), red/pink (28; 1.5%), black/gray (25; 1.3%), and orange (17; 0.9%) were rare in occurrence. Finally, miscellaneous/mixed plastic was recorded 323 times (17.0% of total plastic), primarily in cases when local densities were too high for us to record all data on individual pieces of debris.

Frequencies of some colors of debris plastic differed strongly from those frequencies of neuston plastic (Fig. 15). The greatest difference was in transparent plastic, whose frequency in marine debris was <25% of that in neuston plastic. Similarly, the frequency of black and gray plastic in marine debris was <50% of that in neuston plastic. In

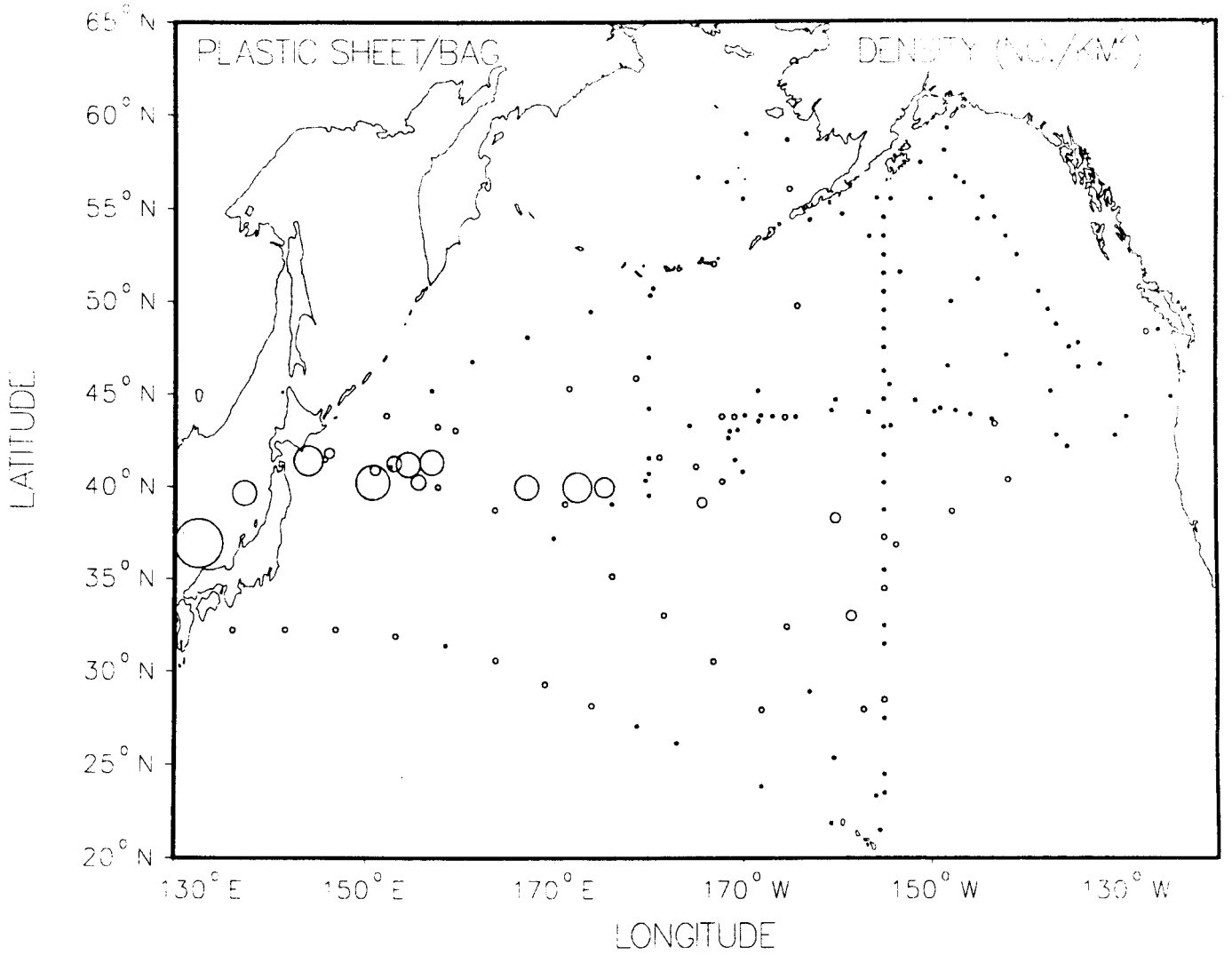

Figure 14.--Densities of plastic sheets and bags, 1984-88. Solid black circles indicate stations at which plastic sheets and bags were not recorded. Sizes of hollow circles indicate relative densities. The highest density was 7.9 pieces/km^2.

contrast, the frequency of white plastic was nearly 33% higher, that of tan plastic was nearly four times higher, and that of yellow plastic was nearly four times higher in marine debris than in neuston plastic. Frequencies of the other colors were relatively similar comparing the two types of plastic.

DISCUSSION

We believe that the present distribution of marine debris is controlled largely by four main phenomena: (1) the heterogeneous geographic

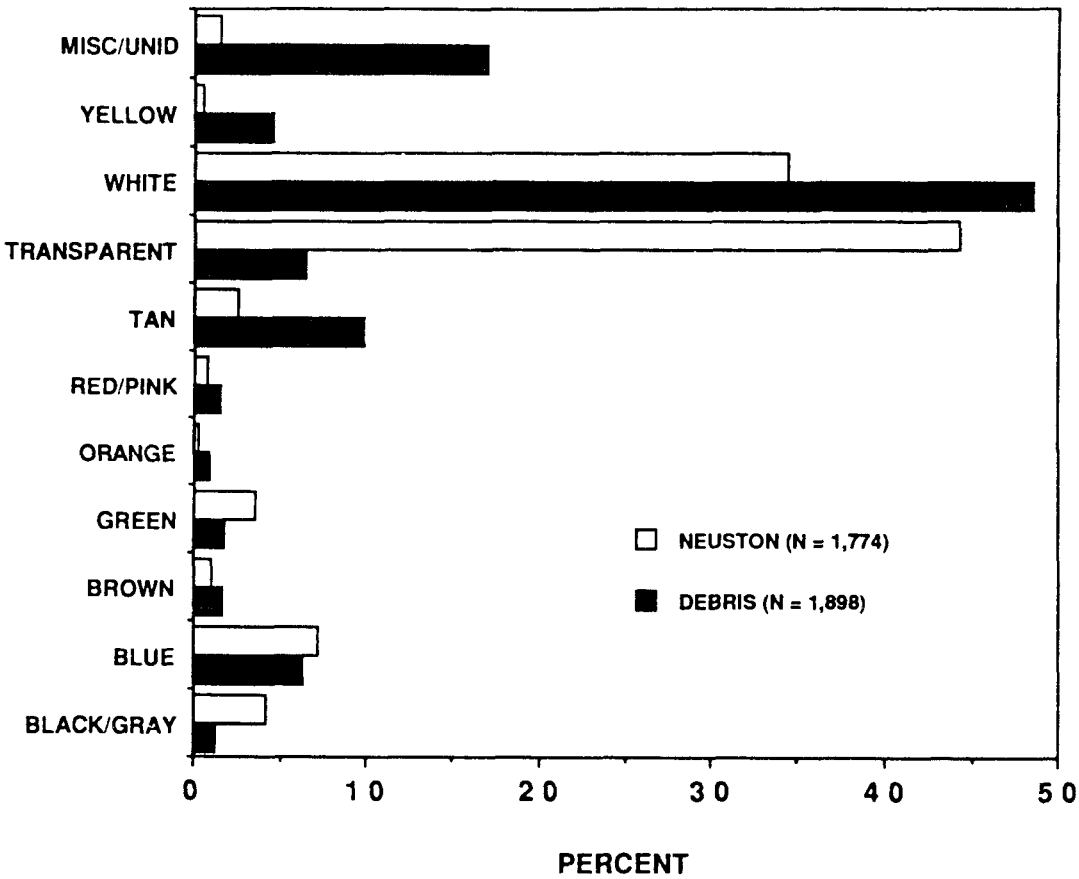

Figure 15.--Frequencies of colors of plastic debris, 1984-88, compared with frequencies of colors of neuston plastic, 1985-88 (the latter data from Day et al. 1990).

input of debris, (2) the subsequent redistribution of that debris by currents and winds, (3) the decomposition of the debris at sea, and (4) the beaching of the debris. The data that we report on here strongly suggest that these factors interact to yield the distributions that we observed. In the absence of precise data on rates of input, transport, and degradation, however, our conclusions about factors controlling marine debris in the North Pacific must be considered tentative.

It is clear that there is heterogeneous geographic input of marine debris, with much originating in the far western Pacific. This conclusion

is supported strongly by the high densities in and around the Japan Sea and nearshore Japan, where the highest densities of both marine debris and neuston plastic (Day et al. 1990) in the North Pacific were recorded. Debris was most abundant in Tokyo Bay (which had far more debris than Day has ever seen elsewhere in the North Pacific--it was too abundant for him to sample) and in localized areas in the Japan Sea. It is unclear to us how much of this debris comes from ships and how much comes from the land. At the other extreme were the Bering Sea and Gulf of Alaska, where low human populations probably provide little input of marine debris.

In Transitional Water to the east of Japan, the importance of transport compared to direct input from ships is difficult to evaluate. The area between lat. 35° and 45°N and from the eastern coast of Japan to long. 145°W is the site of a large pelagic fishery for neon flying squid, *Ommastrephes bartrami*. At the height of the fishery (May-December), approximately 700 gillnetting ships from Japan, Korea, and Taiwan participate (Fredin 1985), as well as an unknown number of small jigging ships. This fishery undoubtedly contributes to marine debris in the area, although its contribution relative to transport is unknown. In contrast, debris entering the ocean around Japan and Korea is moved eastward by the Subarctic Current (in Subarctic Water) and in the Kuroshio (Kawai 1972; Favorite et al. 1976; Nagata et al. 1986) into the same area. In addition to this general eastward movement, Ekman (wind) stress tends to move surface waters from the Subarctic and the Subtropic into the Transitional Water mass as a whole (Roden 1970). As a result, densities of debris in Transitional Water generally are high, but the relative importance of the two sources (i.e., local input and transport into the area) is unclear. Further, the generally convergent nature of surface water in the North Pacific Central Gyre (Masuzawa 1972) should result in high densities there also.

Surprisingly, there are differences among the distributions of types of debris. For example, Styrofoam debris clearly is a "nearshore Japan/transitional/subtropical species" (Fig. 9); neuston Styrofoam also is most abundant around Japan (Day et al. 1990). This localized distribution of Styrofoam may be a consequence of its weak, crumbly texture, which can lead to rapid disintegration; hence, it probably cannot survive long enough to be transported offshore in large quantities. Further, Styrofoam sinks when crushed and waterlogged. Thus, it may be observed only in places where input rates are high. In addition, plastic sheets and bags also seem to be "transitional" (Fig. 14), placing them directly in the range of most of the world's sea turtle species, which readily ingest this type of plastic debris (Balazs 1985). The reason for this distribution of sheets and bags is not known.

The comparison of frequencies of colors of neuston plastic and debris plastic (Fig. 15) suggests a bias in our sampling. Colors that do not contrast strongly with seawater (black/gray, transparent) are underrepresented in debris in comparison with neuston plastic. Although some bias in the color frequency data for neuston plastic probably results from color-selective ingestion of neuston plastic by seabirds (Day et al. 1985), we believe that the difficulty in observing low-contrast debris is the major cause of the differences in Figure 15. Although there is bias in

the debris sighting data, however, densities of debris plastic and neuston plastic are strongly correlated (Day and Shaw 1987). Hence, although absolute estimates of at-sea densities of marine debris plastic are affected by these sighting biases, the debris data presented here provide important information about relative abundances in various parts of the ocean.

Although Fowler (1982, 1985, 1987) claimed that entanglement in lost netting and other marine debris is the major source of mortality of northern fur seals, we find that the data on at-sea densities of lost net fragments are inadequate to determine quantitatively its true importance. We have seen fur seals entangled in net fragments only twice, both in the flying squid fishery and both during fall 1987. The first record was of a fur seal with a trawl net fragment caught over its head at lat. 44°07'N, long. 156°23'W; there were raw, open cuts on the face and gums, although this animal did not appear to be hurt in any way and swam playfully with another unentangled fur seal. The second record was of an immature female fur seal completely entangled in a gillnet fragment at lat. 43°15'N, long. 145°11'W, along with the partially eaten remains of what appeared to be a salmon shark, *Lamna ditropis*, and a yellowtail, *Seriola lalanda*. Thus, sightings of entangled fur seals in derelict net fragments at sea are quite rare, making it difficult to assess the frequency of entanglement. On the other hand, our extensive experience at sea in the North Pacific suggests to us that the probability of entanglement and subsequent mortality of fur seals is higher in nets that actively are fishing for flying squid than in net fragments. The flying squid fishery deploys approximately 3,000,000 km of drift gillnets annually and is concentrated approximately in the zone lat. 39°-46°N (Day unpubl. data). Further, many of the deployments of research nets observed by Day in this area resulted in fur seals' feeding from the nets, climbing on and swimming around the nets, and occasionally becoming caught in the nets. (Most escaped unharmed, however.) Given the high number of entanglements of fur seals in actively fishing gillnets that we have observed, the nearly 60,000 vessel-nights of net deployments in a year, the large amounts of those nets that are fished, and the low number of entanglements in lost net fragments that we have observed in over 21,000 km of observations at sea, we suggest here that the mortality of fur seals from actively fishing nets should be assessed quantitatively and compared to estimates of mortality from derelict nets.

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