DISTRIBUTION AND DENSITY OF FLOATING OBJECTS IN THE NORTH PACIFIC BASED ON 1987 SIGHTING SURVEY

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ABSTRACT

A sighting survey has been conducted in the North Pacific since 1986 to understand the distribution of floating objects there. The survey was conducted on board various types of vessels, including a fisheries research vessel, patrol vessels, training vessels, and commercial freighters, a total of 32 vessels with a distance surveyed of 165,288 nmi.

A total of 46,706 floating objects were recorded in 1987. Of these, fishing net debris accounted for 0.7%, other fishing gears 5.9%, Styrofoam 14.0%, and other petrochemical products 18.3%. The remainder included drifting logs or lumber 7.9%, floating seaweed 42.7%, and other 10.5%.

Density of the objects was generally high in the coastal waters, but high density was also observed in areas between lat. 25° and 30°N, and long. 170° and 130°W. It is assumed that floating objects transported from various areas by ocean currents accumulated here. A belt-shaped low-density area was observed between lat. 45° and 50°N.

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

A total of 32 vessels, vessels which belong to the Fisheries Agency of the Government of Japan, training ships of fishery high schools and universities, and cargo transport ships, participated in a sighting survey of floating objects in the North Pacific (Table 1). The total distance for which the sightings were conducted was 165,228 nmi, and 46,706 items of marine debris were sighted during the cruises.

This survey has been repeated continuously since 1986, with the objectives of defining patterns of marine debris, clarifying the conditions of distribution, and determining the actual volume of various types of debris floating in the sea. Although the areas surveyed extended to the Sea of Japan, Yellow Sea, South Pacific Ocean, and Gulf of Mexico, this report concentrates on the North Pacific and its adjacent waters.

METHODS

Methods of sighting and items of observation were the same as in the previous year (Mio and Takehama 1987), except for the addition of the size of debris items observed. Size is described as follows. We measured with the eye the length of the longest piece of marine debris and recorded that S = <50, M = 50-200, and L = >200 cm.

RESULTS

Outline of Results

The distribution pattern of the cruising distance for the surveys (henceforth referred to as effort) shows that effort was high in Japanese waters and in the western Pacific, and low in the eastern and southern Pacific (Fig. 1). By season, 57.7% of the entire effort was expended during the 4 months from June to September. In the other months, excluding December, 4 to 8% of the effort was expended.

Looking at marine debris by kind (Table 2), 310 pieces of fishing net were recovered, 0.7% of all marine debris found (gillnet 0.2%, trawl net 0.1%, and unidentified net 0.4%). The proportion of fishing gears other than nets was somewhat larger (5.9%) and accounted for 15.3% of the total petrochemicals (fishing nets, other fishing gears, Styrofoam, and other plastic debris). Styrofoam accounted for 36% of all petrochemicals and for 14% of all marine debris, being the most abundant single material. Sheets and bags made of nylon and vinyl, and other plastic debris represented by containers for detergent and drinking water, accounted for 18.3% of the total marine debris and for 47.0% of the total petrochemicals. The number of their sightings was large, and they were quantitatively the major item of marine debris. Among biodegradable marine debris, pieces of wood and drifting logs accounted for 7.9%, and floating seaweed accounted for 42.7%. Other consisted mainly of glass products and empty cans, and accounted for 10.5%.

Table 1.--Vessels engaged in marine debris sighting survey in 1987.

Name of vessel	Gross tonnage	Horsepower	Area of survey[a]	Cruising distance (nmi)	Number of debris pieces sighted
Kotaka Maru	47	235	J	648.9	2,319
Tankai Maru	157	900	J	2,758.8	296
Hokko Maru	466	1,800	J P	9,435.1	971
Wakataka Maru	170	540	J	3,618.9	1,325
Soyo Maru	494	1,600	J	6,286.1	3,221
Yoko Maru	499	1,600	J	5,363.6	1,341
Mizuho Maru	150	900	J	4,979.2	3,094
Shunyo Maru	393	2,600	J	7,156.6	1,340
Shoyo Maru	1,362	2,000	J P	14,857.4	2,798
Kaiyo Maru	2,644	3,800	J P	9,940.2	179
Wakatake Maru	427	1,500	J P	4,166.7	259
Shin Riasu Maru	471	1,400	J P	12,194.9	910
Wakasio Maru	199	900	J	1,285.3	448
Hoyo Maru No. 12	284	1,000	J P	4,134.4	663
Kanki Maru No. 58	96	470	J P	4,337.7	229
Hokuho Maru	441	1,300	J P	7,281.7	654
Shirafuji Maru	138	1,000	J	386.0	876
Osyoro Maru	1,779	3,200	J P	4,018.5	166
Hoksei Maru	893	2,100	J P	4,057.2	236
Tansu Maru	444	1,500	J	1,561.9	779
Omi Maru	417	1,300	J P	4,485.1	107
Shirahagi Maru	366	2,600	J P	6,903.4	305
Toko Maru	1,513	8,000	J P	12,845.6	343
Hakuryu Maru	517	2,500	J P	4,086.7	230
Coop	2,445	3,800	J	1,237.6	52
Sunbelt Dexie	11,447	14,000	J P	5,366.6	15,387
Nichiyo Maru	995	3,000	J P	1,176.7	4,673
Kumamoto Maru	380	1,600	J	3,599.2	598
Riasu Maru No. 1	476	1,100	J P	11,732.4	251
Hoyo Maru No. 78	300	440	J P	5,294.1	885
Taisei Maru No. 55	350	3,400	J P	725.2	449
Tosi Maru No. 15	730	3,600	J	3,803.5	1,974

[a]J = Japanese waters north of lat. 20°N and west of long. 160°E;
P = Pacific area other than Japanese waters.

Effects of Environmental Conditions

In order to study the effects of luminous intensity and waves on the sighting survey, the numbers of sightings by wind force and by time of day were examined comparatively for eight vessels which had conducted surveys for a fairly long time in the area where the effort expended was largest (lat. 40° to 45°N and long. 140° to 150°E).

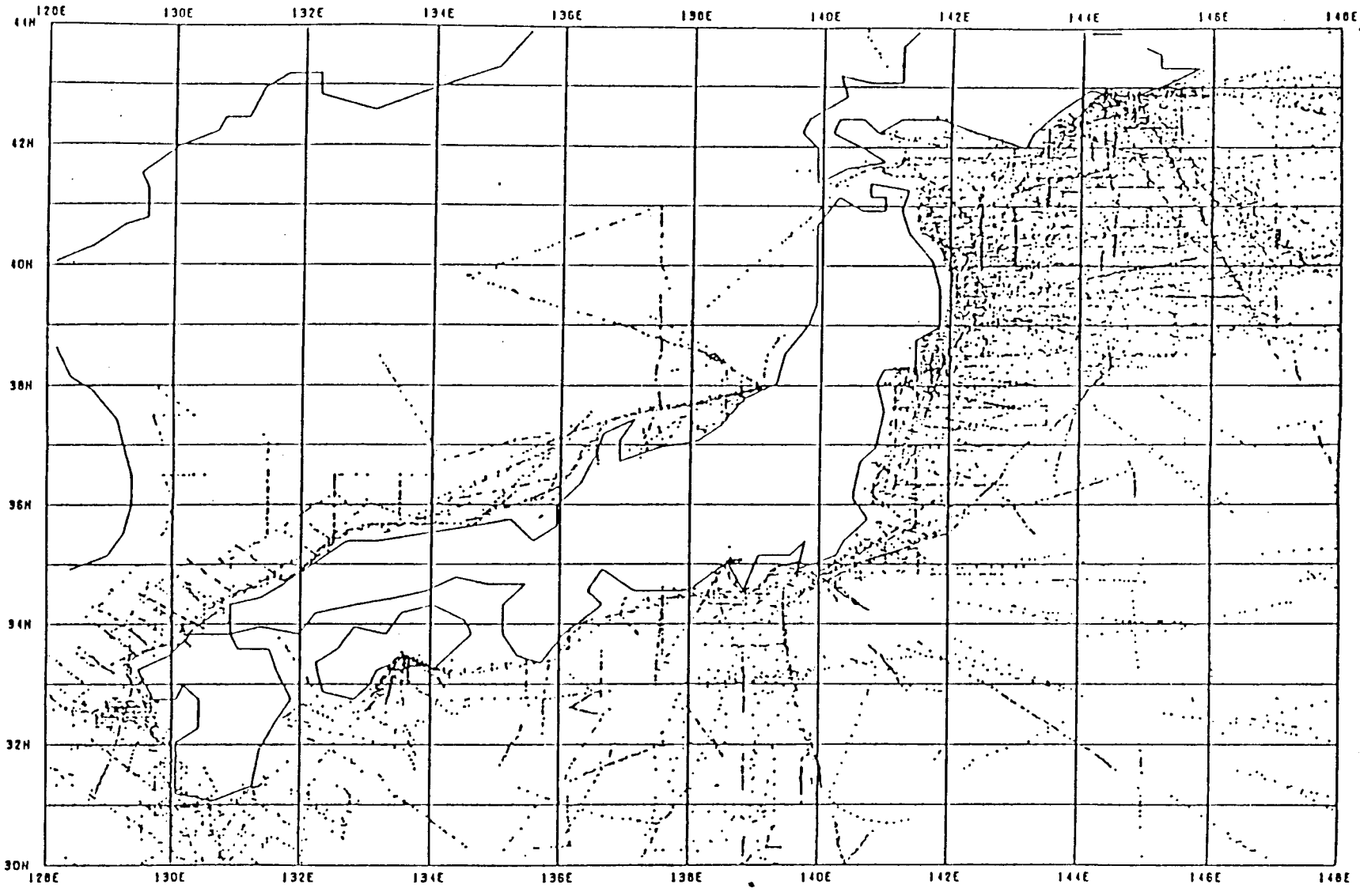

Figure 1A.--Tracks of vessels engaged in marine debris sighting survey in 1987, coastal waters of Japan.

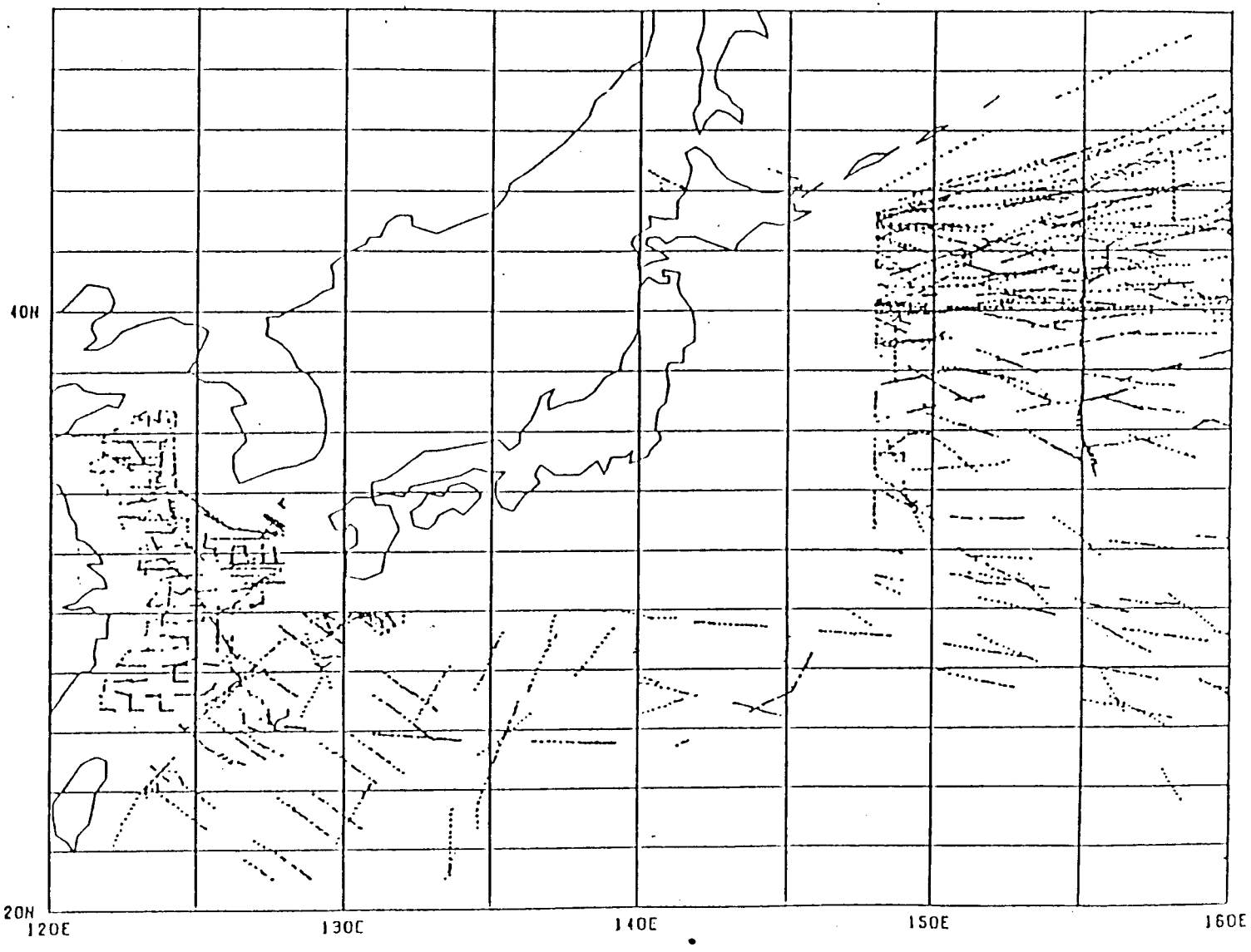

Figure 1B.--Tracks of vessels engaged in marine debris sighting survey in 1987, neighboring waters of Japan.

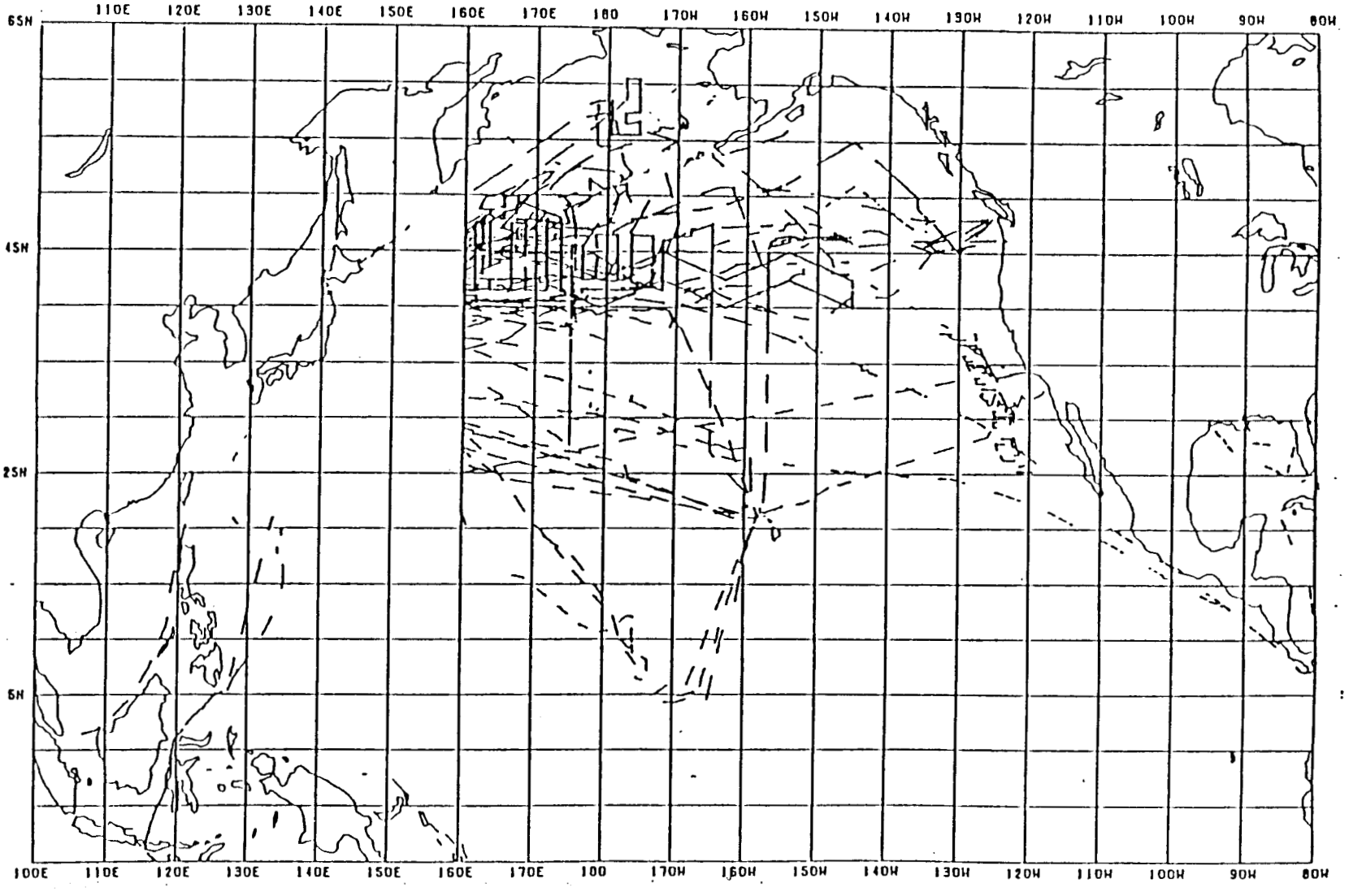

Figure 1C.--Tracks of vessels engaged in marine debris sighting survey in 1987, Pacific high seas area.

Table 2.--Number of debris items sighted, by month and type of debris.

Month	Cruising distance (nmi)	Type of debris									
		Fishing net			Other fishing gear	Styrofoam	Other plastic debris	Wood	Floating seaweed	Others	Total
		Unknown	Trawl	Gill							
January	7,857.3	--	--	--	18	30	12	192	169	151	582
February	7,832.1	4	--	2	38	128	85	34	32	31	354
March	8,813.8	2	--	--	104	415	115	88	709	394	1,827
April	6,819.6	4	2	5	134	360	208	207	884	62	1,875
May	11,181.7	4	2	2	169	334	131	90	257	221	1,210
June	28,435.9	13	14	7	313	752	1,020	1,172	2,192	833	6,617
July	31,323.2	23	5	6	344	724	958	314	1,601	296	4,266
August	20,184.3	19	8	9	315	873	799	295	781	309	3,408
September	18,743.9	44	25	14	567	1,136	1,500	507	4,951	627	9,371
October	13,030.9	31	3	19	282	1,162	2,761	612	7,987	1,784	14,641
November	9,840.1	27	1	13	459	541	901	141	374	162	2,619
December	1,225.2	2	--	--	31	97	59	20	14	13	236
Total	165,287.9	173	60	77	2,774	6,552	8,544	3,672	19,951	4,893	46,706

Wind Force

The evidence suggests that the number of debris items sighted per unit of effort (100 nmi) is inversely related to wind force (Beaufort scale). The maximum sightings occurred at wind force class 1 and sightings decreased as the wind force increased (Fig. 2).

Only five vessels conducted sightings surveys in wind force class 1. This effort was extremely small compared to the effort in wind force classes 2 to 5, and was only 11% of wind force class 3, which had the largest effort. Wind force which showed maximum effort varied by vessel; in the case of *Shoyo Maru*, wind force exceeding class 6 showed maximum effort. Although as a general trend the number of sightings decreased as wind force increased, the number of sightings also varied by type of vessel and kind of marine debris.

Luminous Intensity

Time of day was used as an index of luminous intensity, and data from the same time of day were compared for sighting of marine debris (Fig. 3). Using the average value of the same eight vessels, the number of sightings decreased after 1200 (time of the maximum value); the rate of decrease remained within 60%, except at 1700. Five vessels showed the maximum value between 1200 and 1400, but for the *Hokko Maru* the maximum value was obtained at 1700, and for the *Shoyo Maru* the maximum value was obtained at 0600. These findings suggest that the number of sightings by time were related to many elements, and no clear trend by time was recognized. It is considered that there was no time of day at which it was extremely difficult to find marine debris.

Sighting Rate by Distance

In this survey, we usually observed at close range from the stern the distances and angles each debris items sighted. The distance at right angles to the track of the vessel (right angle distance) was measured, and marine debris was collected by category (Fig. 4). The number of sightings decreased as the right angle distance increased, and the number of sightings per 10 m accounted for <5% when the distance exceeded 100 m. Therefore, in estimating the number of sightings, the sighting width of 200 m, 100 m on each side of the track, was also estimated.

The relationship between right angle distance and the number of sightings of marine debris indicated a distribution with the maximum value of 10 to 20 m except for pieces of wood and drifting logs. Since the position of the marine debris never changed and never showed any movement against the vessel, it was easier to spot marine debris that was closer to the observers. If an observer could stop and scan the sea completely, the number of sightings would likely be in proportion to the distance. However, when sightings are conducted from a moving vessel it is not always possible to find marine debris close to the observer. As the vessel is sailing, the closer the debris is to the observer, the shorter the time in which it remains in the observer's visual field. Also it is not possible

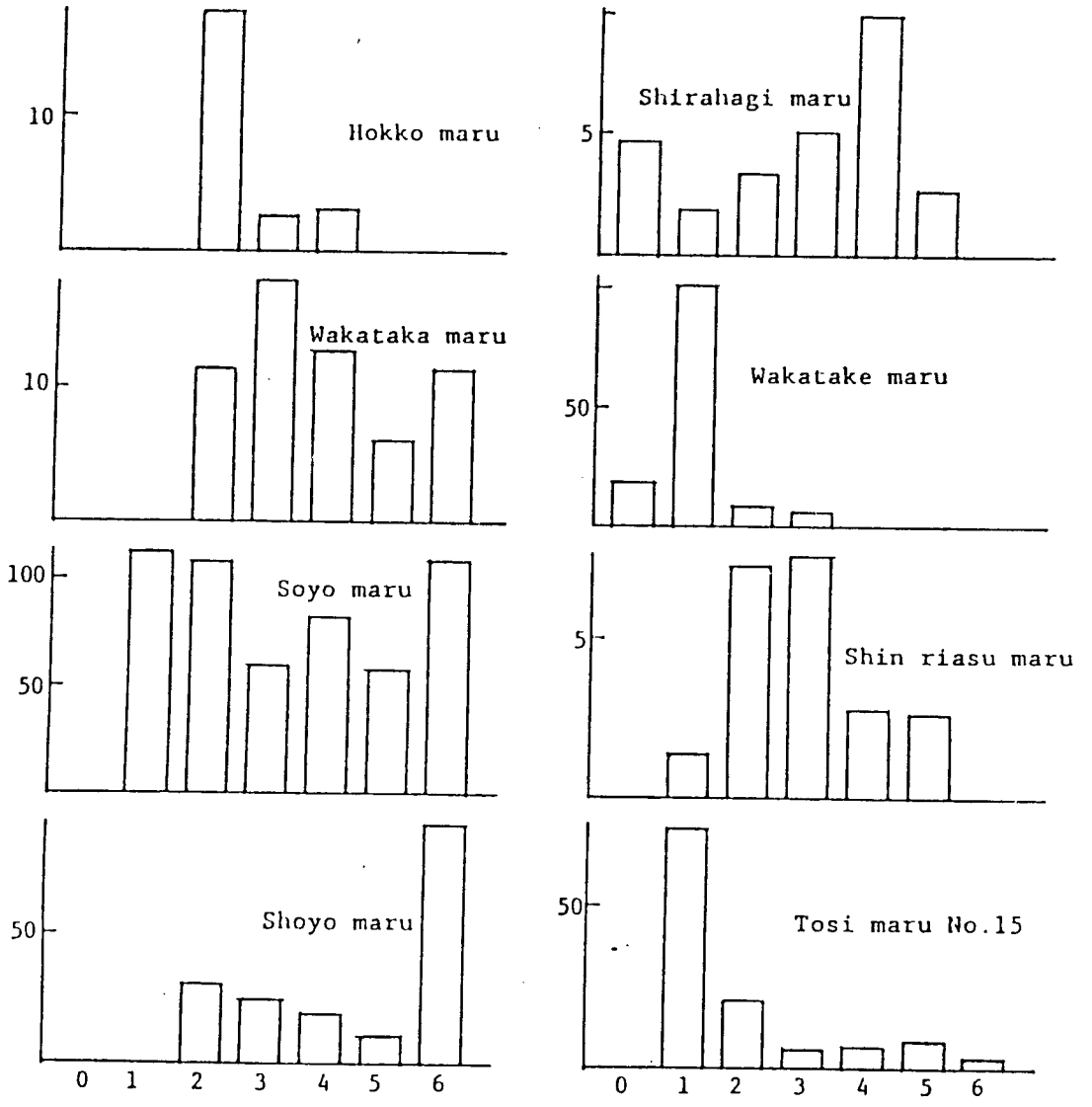

Figure 2.--Number of marine debris pieces sighted per 100 nmi in terms of wind force (Beaufort scale) for each vessel.

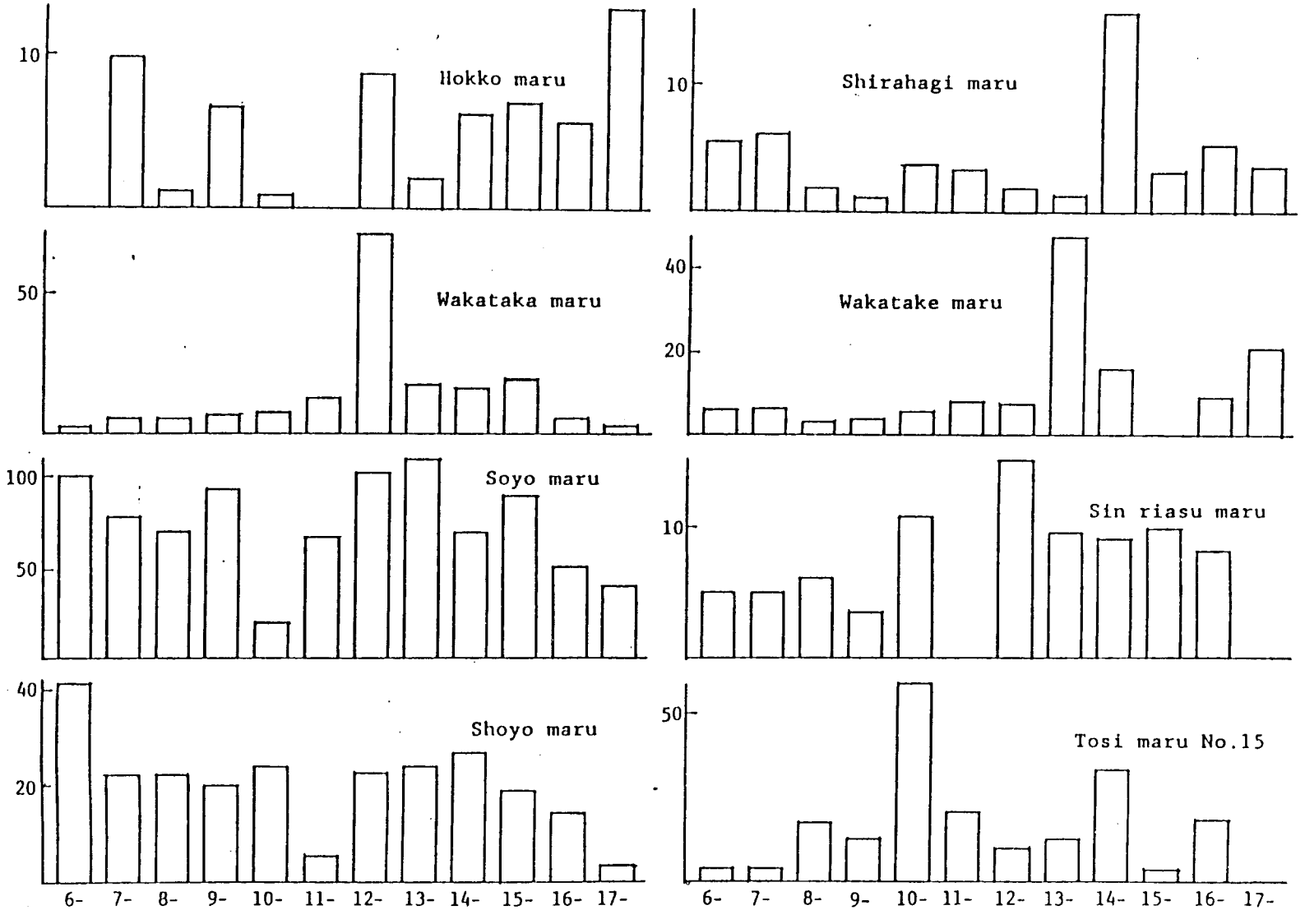

Figure 3.--Number of marine debris pieces sighted in terms of time of observation for each vessel.

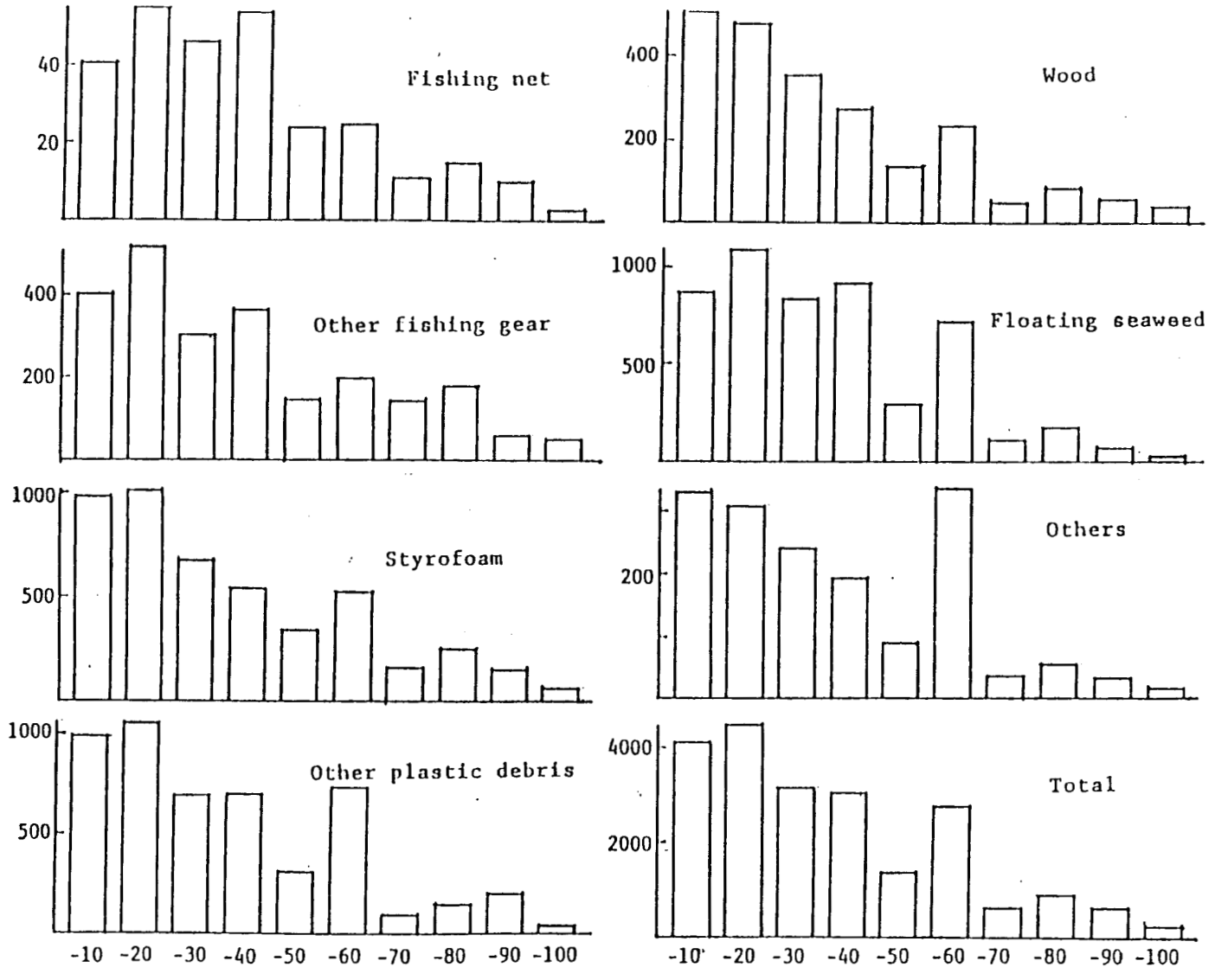

Figure 4.--Number of marine debris pieces sighted in terms of right angle distance (in meters) by type of debris.

to find marine debris on the sea when it is hidden behind the vessel. It is thought that there is a preferred distance for finding marine debris when the sighting is conducted from a fixed position. This was determined by the fact that in comparison with the sightings in Japanese waters and those in the Pacific Ocean, the number of sightings at a distance of 10 to 20 m tended to be larger than the number of sightings at a distance of 0 to 10 m.

Vessels conducting surveys in the Pacific Ocean were larger in size and had higher speeds than vessels conducting surveys in Japanese waters only. For the above two reasons, it is considered to be more difficult to observe the surface of the sea that is closer to the vessel. In addition, a decrease in the number of sightings in the range of 0 to 10 m was also caused by errors which arose from rounding to the nearest whole number when the angles sighted were reported. That is, as an angle was measured with the eye, the article which was recognized in the range of 0° to 5° was mostly reported as at 5°. If a distance sighted exceeded 115 m, marine debris was located from 10 to 20 m in right angle distance. For the optimum distance sighted in the relationship between right angle distance and number of sightings, it is necessary to collect more data and to continue further studies. In this report, the effective width was calculated from the assumption that the sighting probability on the path is 1.

Distribution Density of Marine Debris

Relationship between right angle distance (Y) and sighting rate (g(Y)) is shown in the following curvilinear equation:

$$g(Y) = 1 - \mathrm{Exp}\ (-(Y/A)^{(1-B)}).$$

The coefficients of each type of marine debris are shown in Table 3.

The number of individual items per unit area for each type of marine debris was calculated by blocks (5° of latitude by 10° of longitude) on the basis of the following equation (Seber 1982):

$$N = \frac{nf(0)}{2L}\ .$$

N = Number of individuals per unit area.
n = Number sighted.
L = Steaming distance.
f(0) = 1/effective width.

Figure 5 shows the number of individual items per unit area by block obtained in this manner, and by the type of marine debris.

Table 3.--Coefficients of each type of marine debris.

Type of marine debris	A	B	f(0)
Fishing net	46,099	4,178	0.01752
Other fishing gear	39,623	3,627	0.01923
Styrofoam	41,598	3,969	0.01891
Other petrochemical products	46,366	4,613	0.01779
Pieces of wood and drifting logs	38,330	4,165	0.02060
Floating seaweed	47,890	5,679	0.01797
Other	31,485	3,565	0.02331
Total debris	38,162	3,430	0.01951

DISCUSSION

Distribution of Effort

A glance at the distribution of effort by block tells its own story: The blocks where effort was expended abundantly were concentrated in Japanese waters (Fig. 6). There were three blocks in which the survey distance exceeded 10,000 nmi, and the blocks which exceeded 3,000 nmi were also restricted to Japanese waters and adjacent areas. Next to the Japanese waters and adjacent areas, the offshore area of California, the southern area of the Alaska Peninsula, and the Northwestern Hawaiian Islands were also areas in which a large amount of effort was expended. However, the former two areas were also completely surveyed, one by the *Kaiyo Maru* only and the other by the *Toko Maru* and the *Shin Riasu Maru*, respectively, and the survey season was biased. As the Northwestern Hawaiian Islands are in the path of vessels which come and go from Honolulu, the area of survey is restricted.

Furthermore, glancing at numbers sighted by block, even blocks of other plastic debris, which has the most abundant sightings, the blocks in which 50 or more petrochemical items were found were only 18.4% of the total number of blocks in which petrochemicals were found. In order to obtain reliable density of marine debris, ideally speaking, it is necessary to conduct surveys evenly throughout the blocks in each season. As we mentioned before, in the present surveys, effort is frequently biased by season and by block, and the number of reliable blocks are extremely few. However, we calculated tentative density using the results of sightings as they were obtained.

Distribution of Marine Debris by Type

There were only 310 individual sightings of fishing nets, and reliable results were not obtained. However, the blocks in which sighting density was high were from lat. 25° to 40°N and long. 170° to 130°W, and in that area the density increased toward the east. Sighting density was next highest in Japanese waters and the East China Sea, but was only 2% of the block in which the density was the highest. In waters of lat. 45° to 50°N,

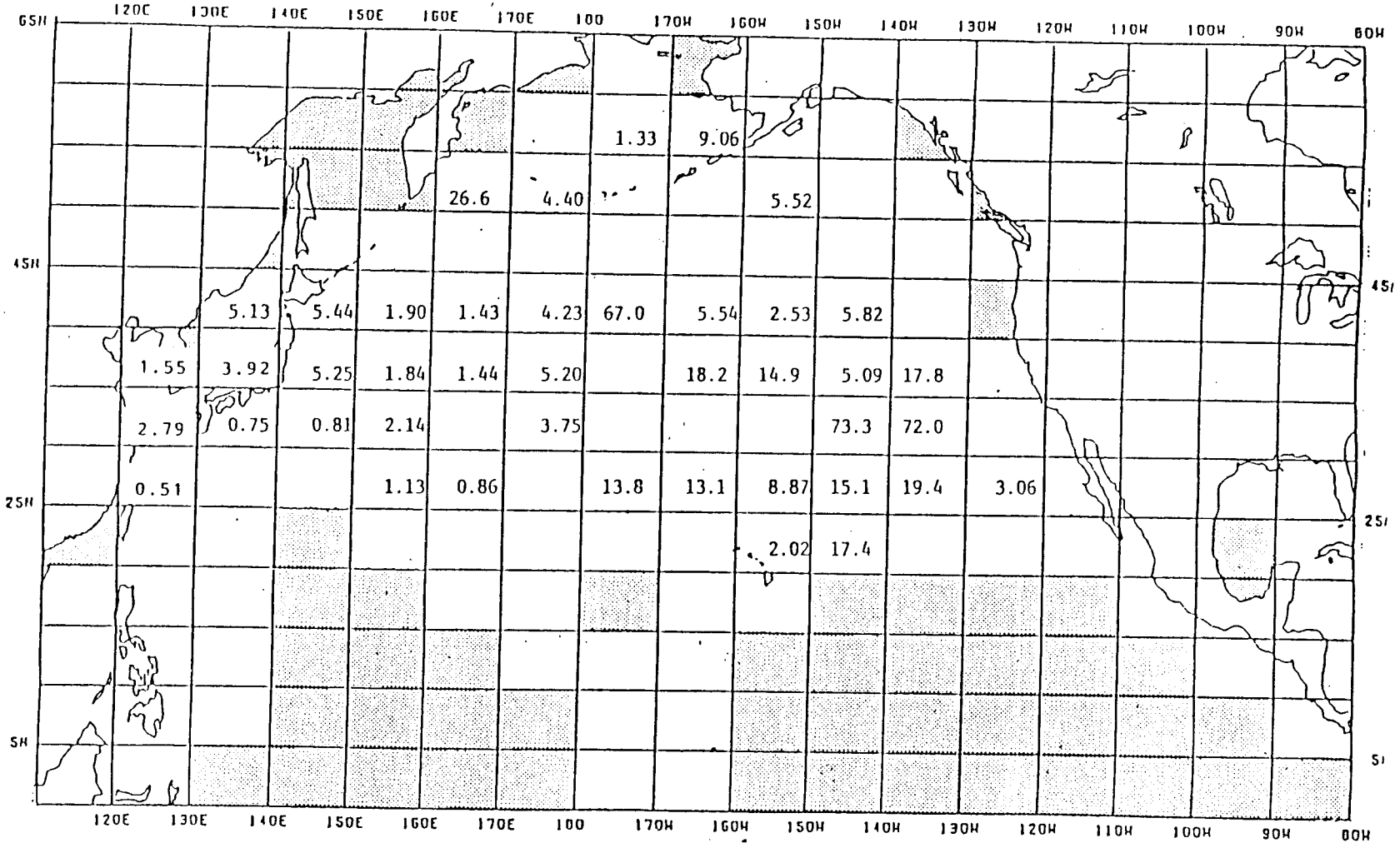

Figure 5A.--Estimated density distribution of fishing net debris in 1987. Unit: number of debris pieces $\times 10^{-1}$ per 1 nmi^2.

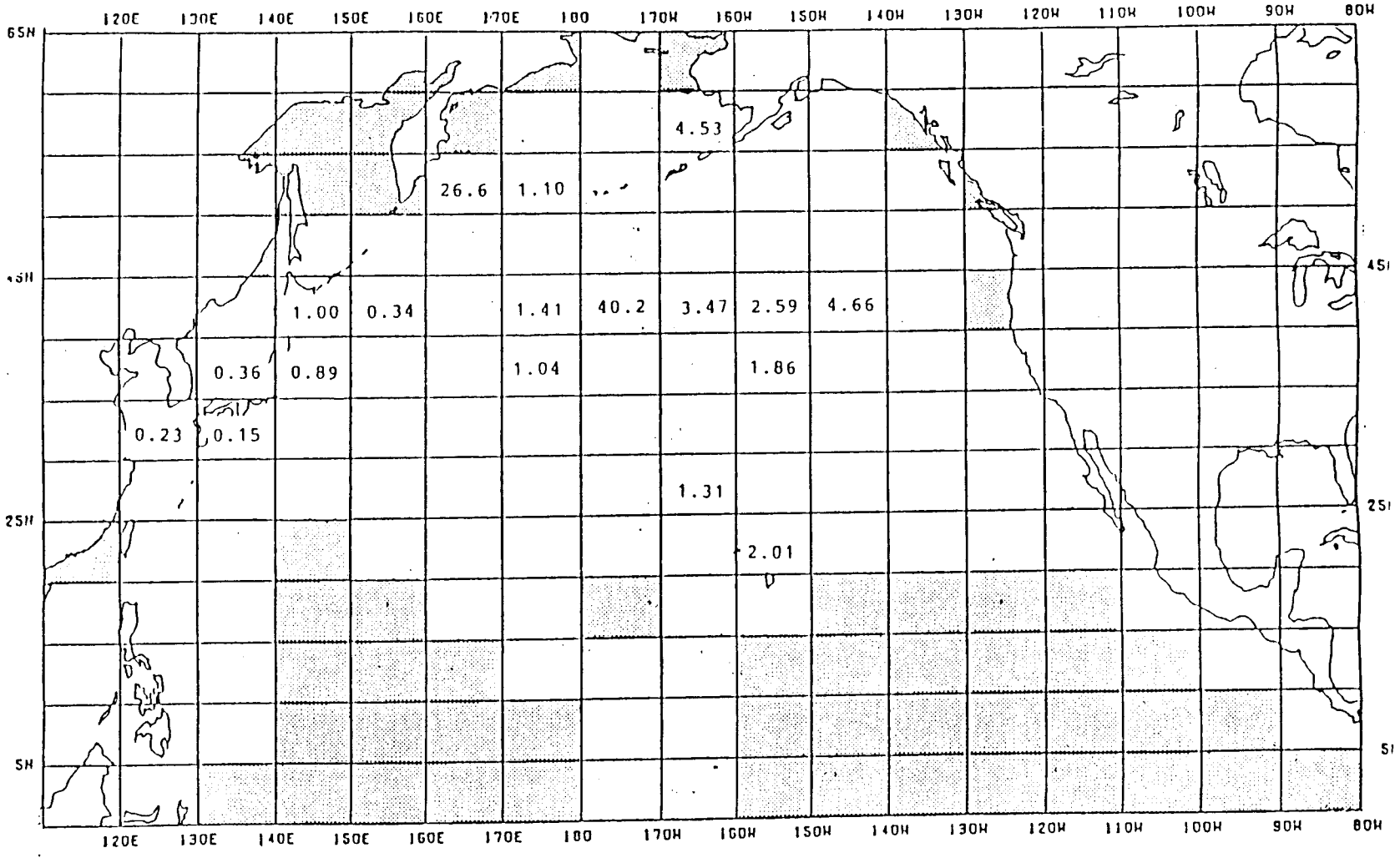

Figure 5B.--Estimated density distribution of trawl net debris in 1987.
Unit: number of debris pieces $\times 10^{-1}$ per 1 nmi^2.

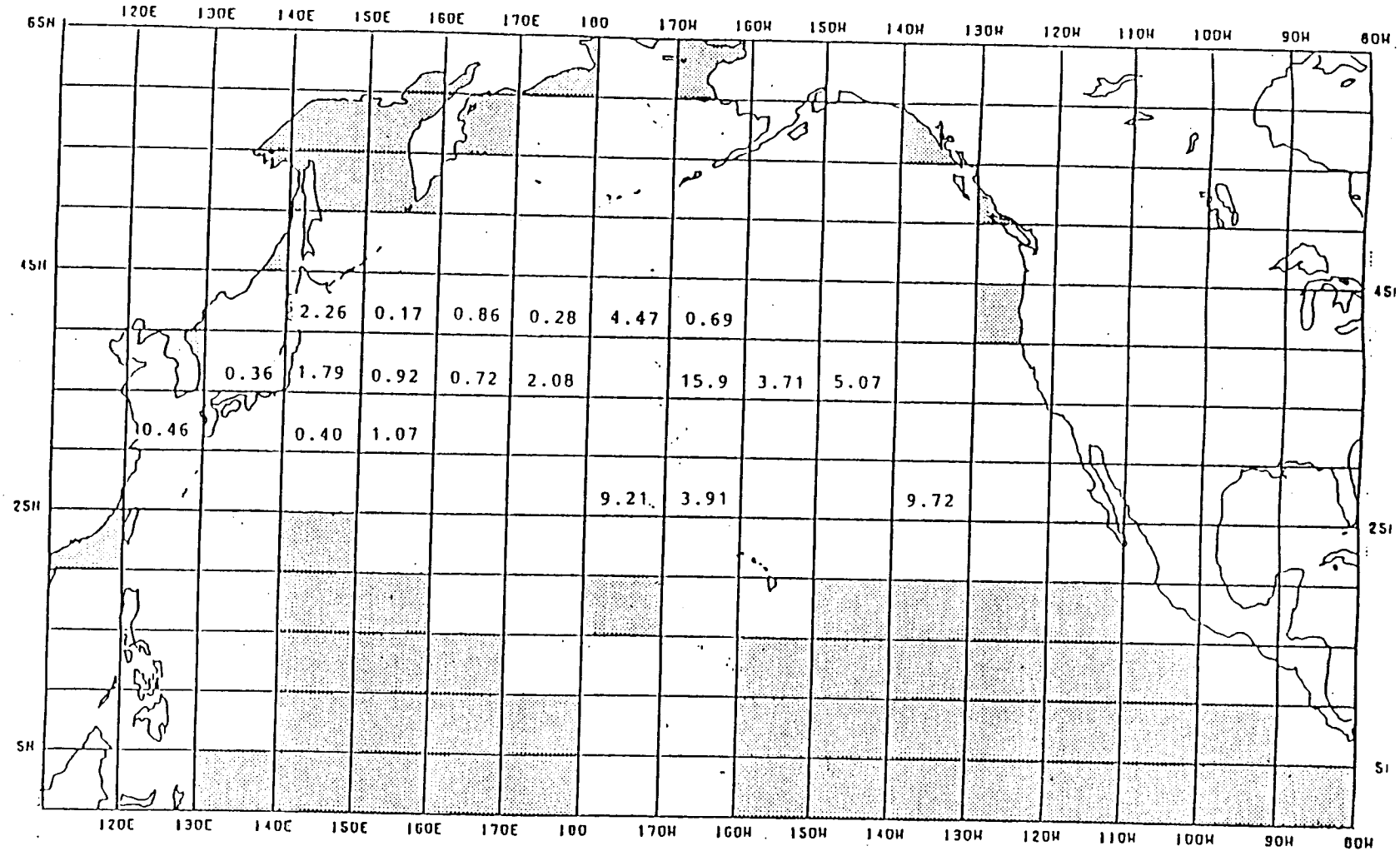

Figure 5C.--Estimated density distribution of drift net debris in 1987. Unit: number of debris pieces x 10^{-1} per 1 nmi^2.

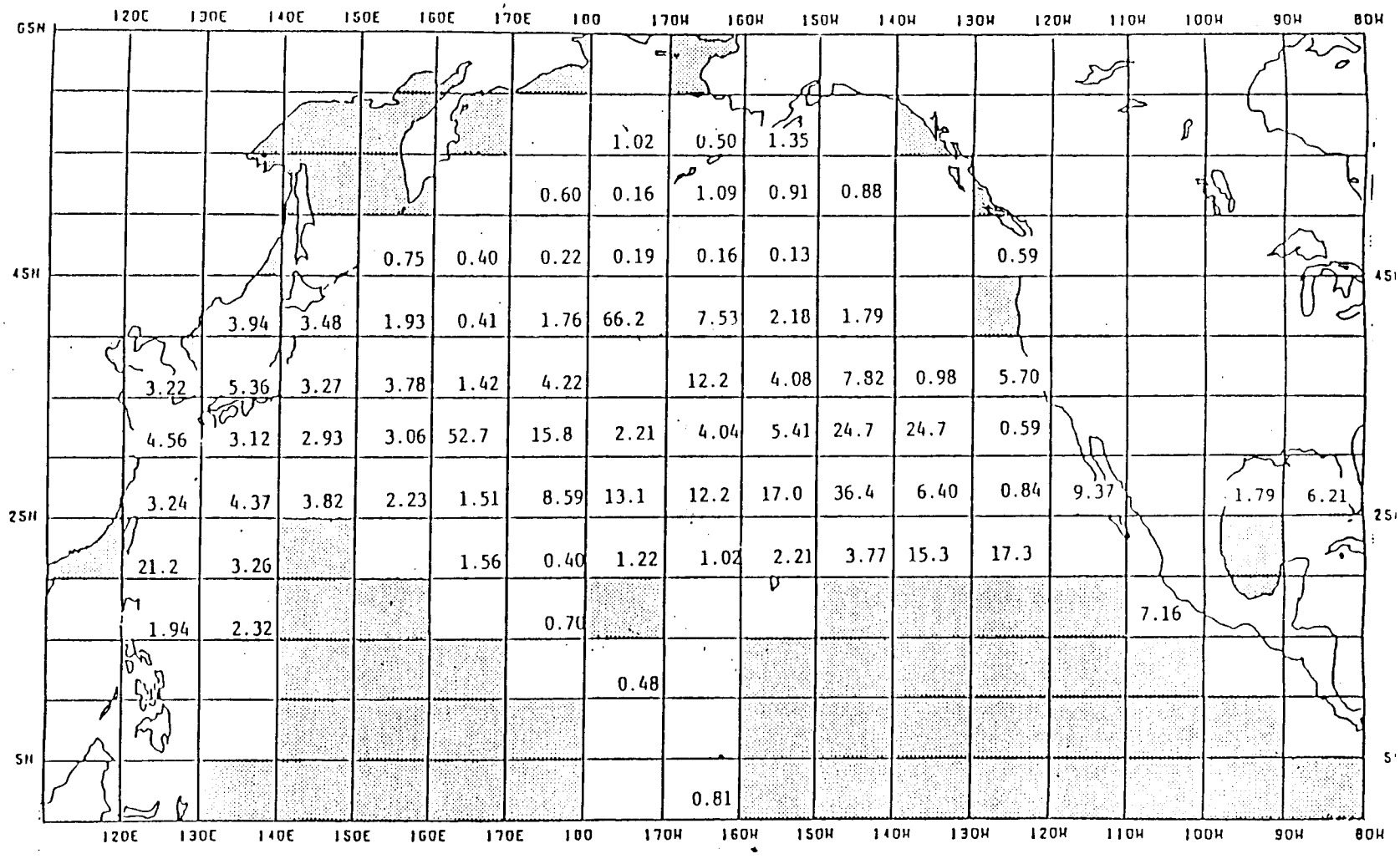

Figure 5D.--Estimated density distribution of other fishing gear debris in 1987.
Unit: number of debris pieces x 10^{-1} per 1 nmi^2.

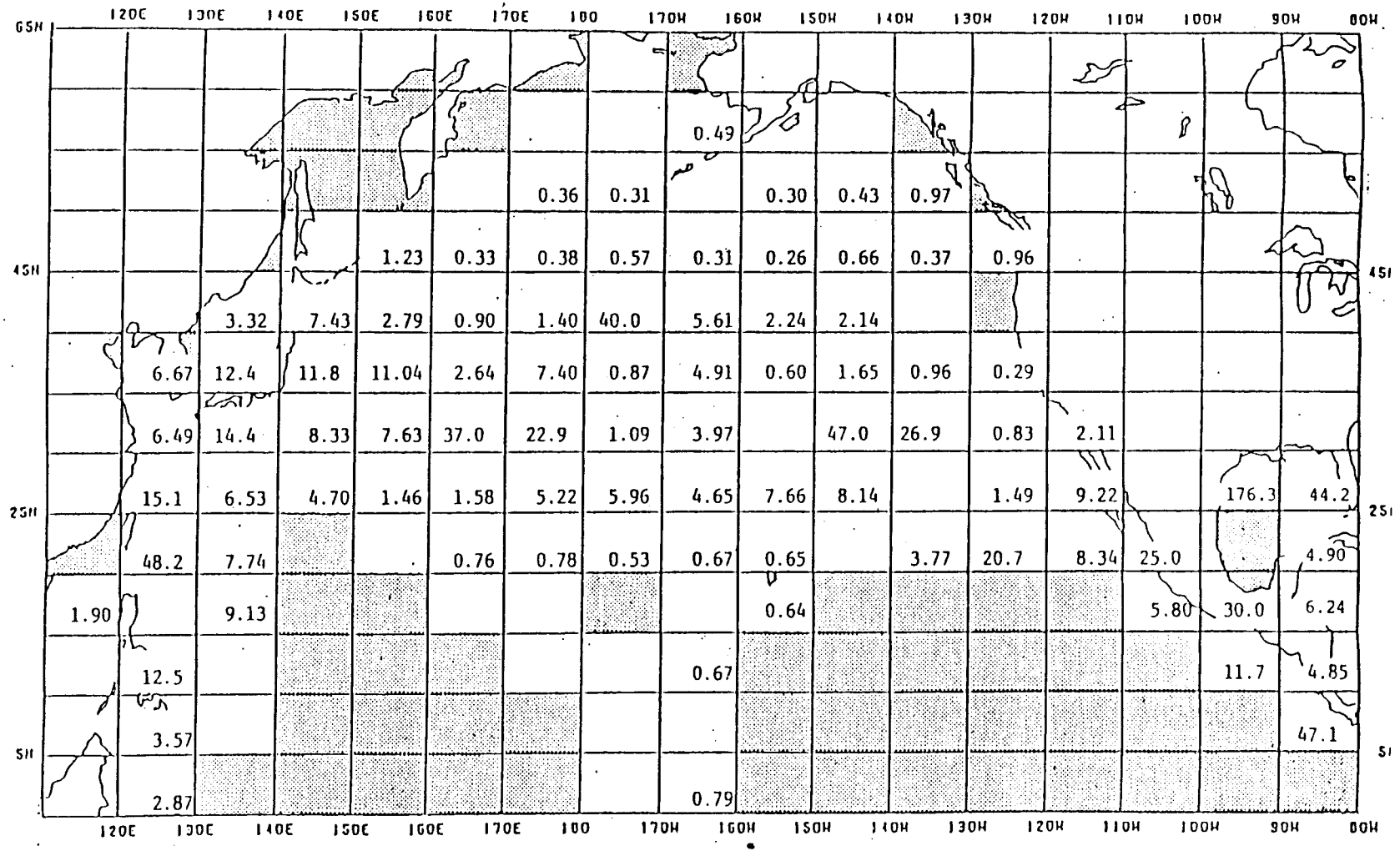

Figure 5E.--Estimated density distribution of Styrofoam debris in 1987.
Unit: number of debris pieces × 10^{-1} per 1 nmi^2.

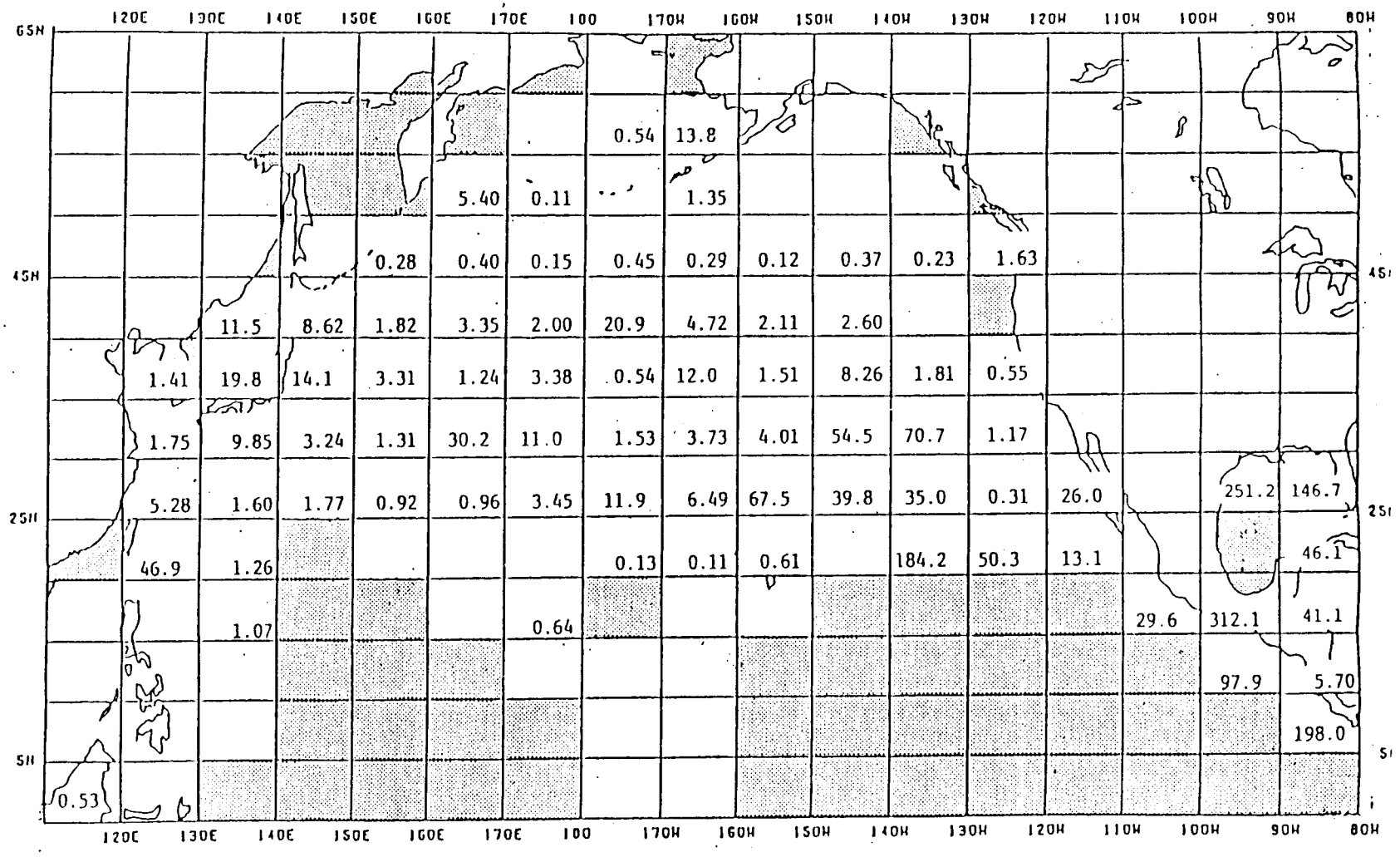

Figure 5F.--Estimated density distribution of other plastic debris in 1987.
Unit: number of debris pieces $\times 10^{-1}$ per 1 nmi^2.

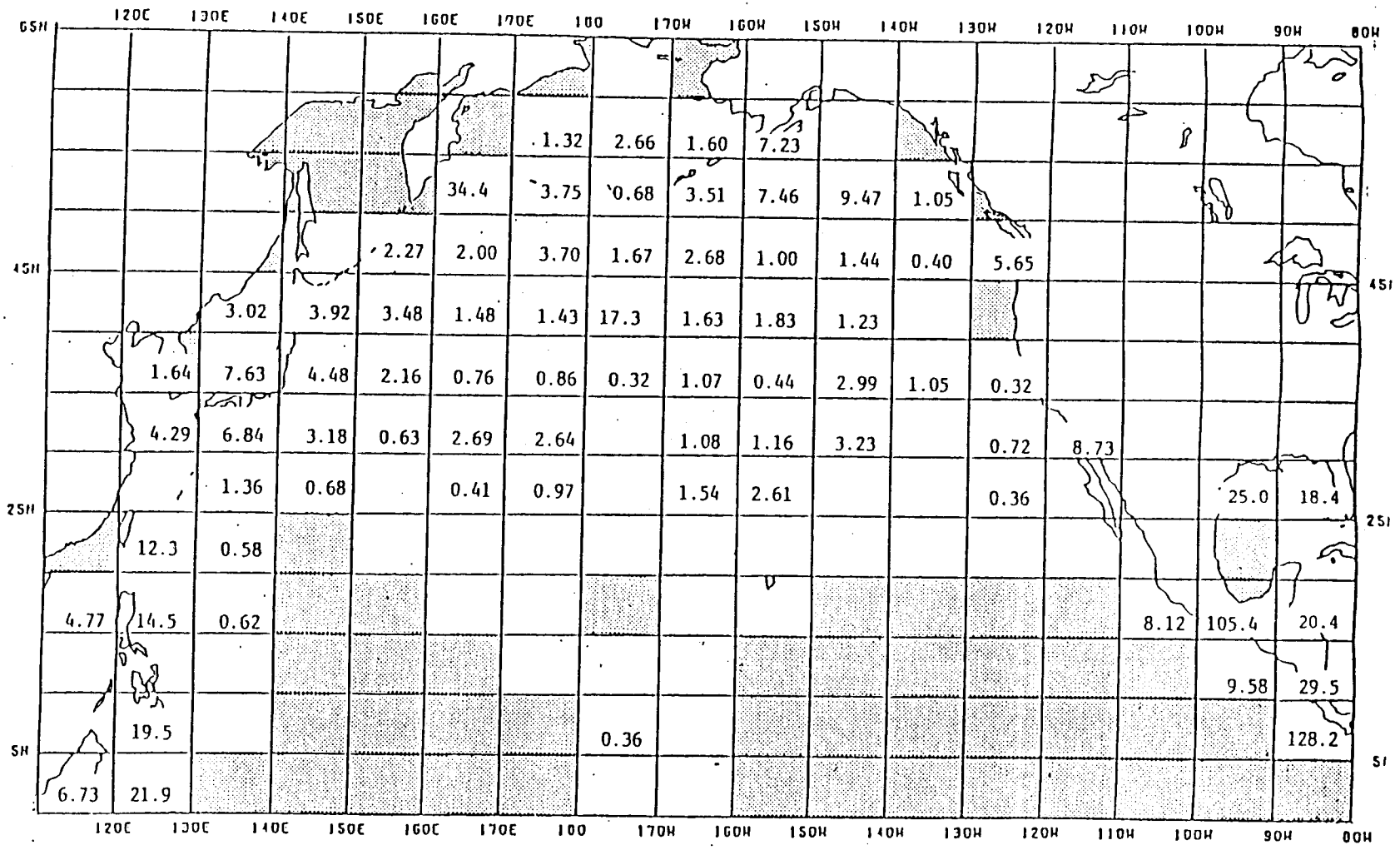

Figure 5G.--Estimated density distribution of wood debris in 1987.
Unit: number of debris pieces × 10^{-1} per 1 nmi^2.

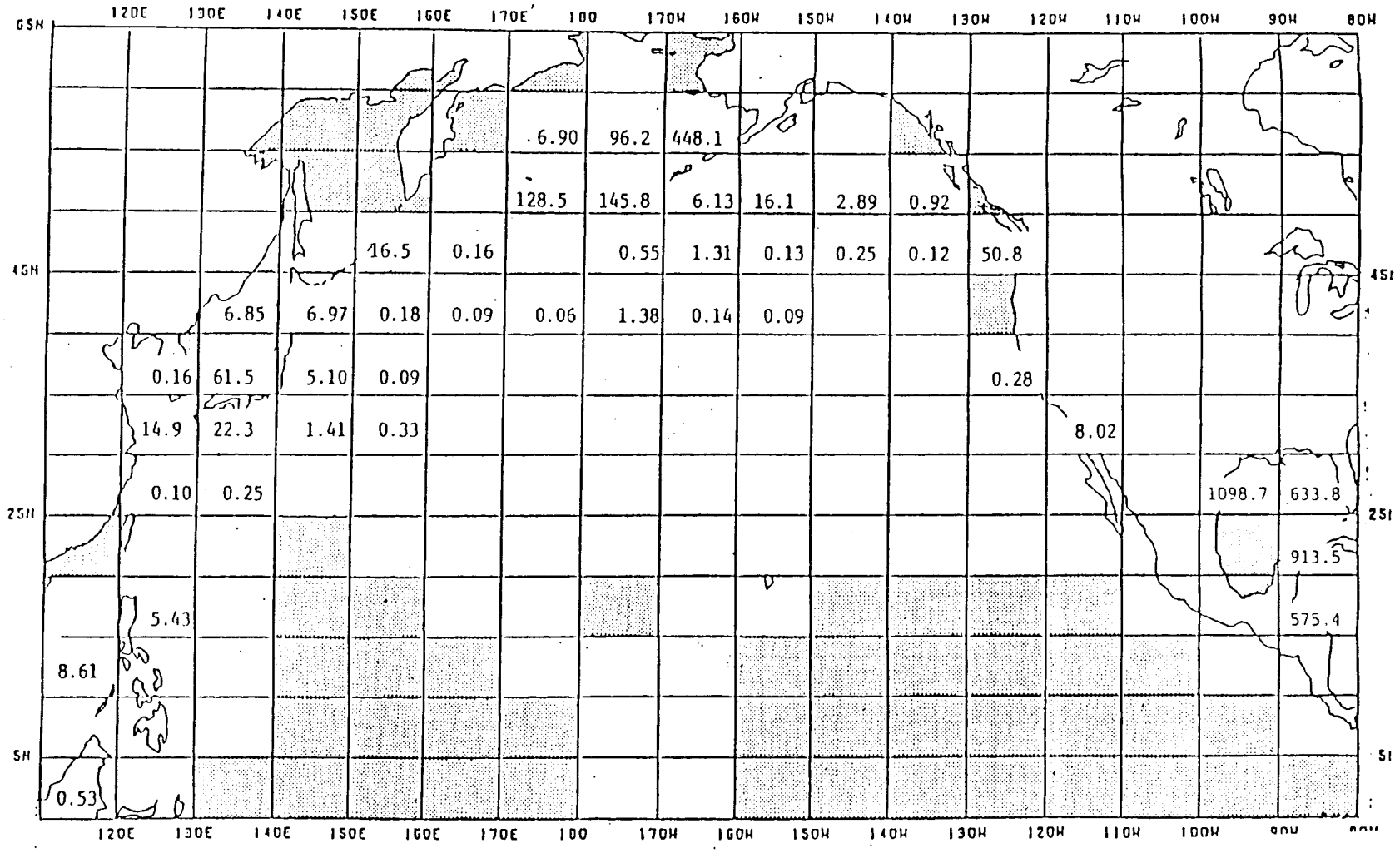

Figure 5H.--Estimated density distribution of floating seaweed debris in 1987.
Unit: number of debris pieces × 10^{-1} per 1 nmi^2.

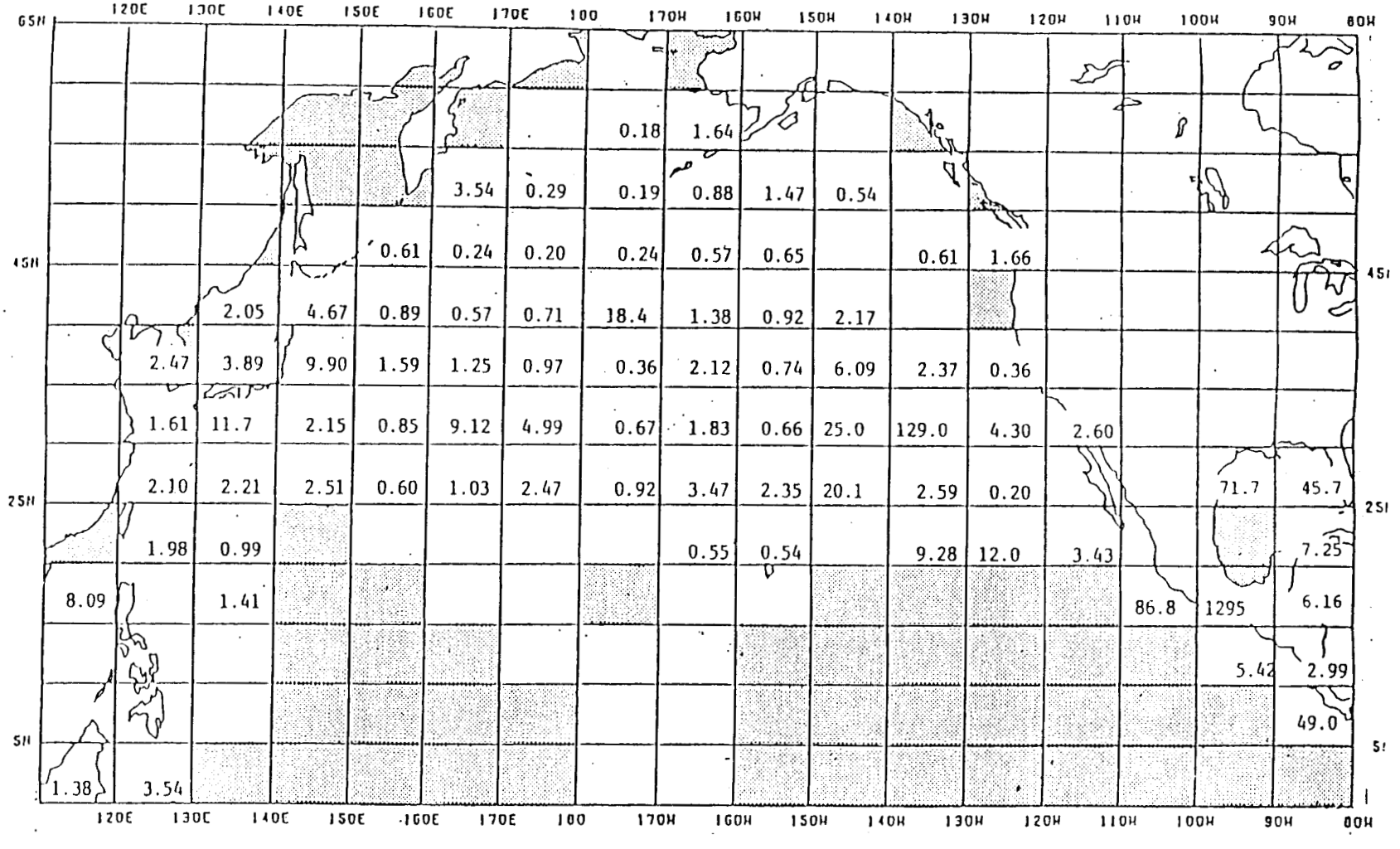

Figure 5I.--Estimated density distribution of other marine debris in 1987.
Unit: number of debris pieces $\times 10^{-1}$ per 1 nmi^2.

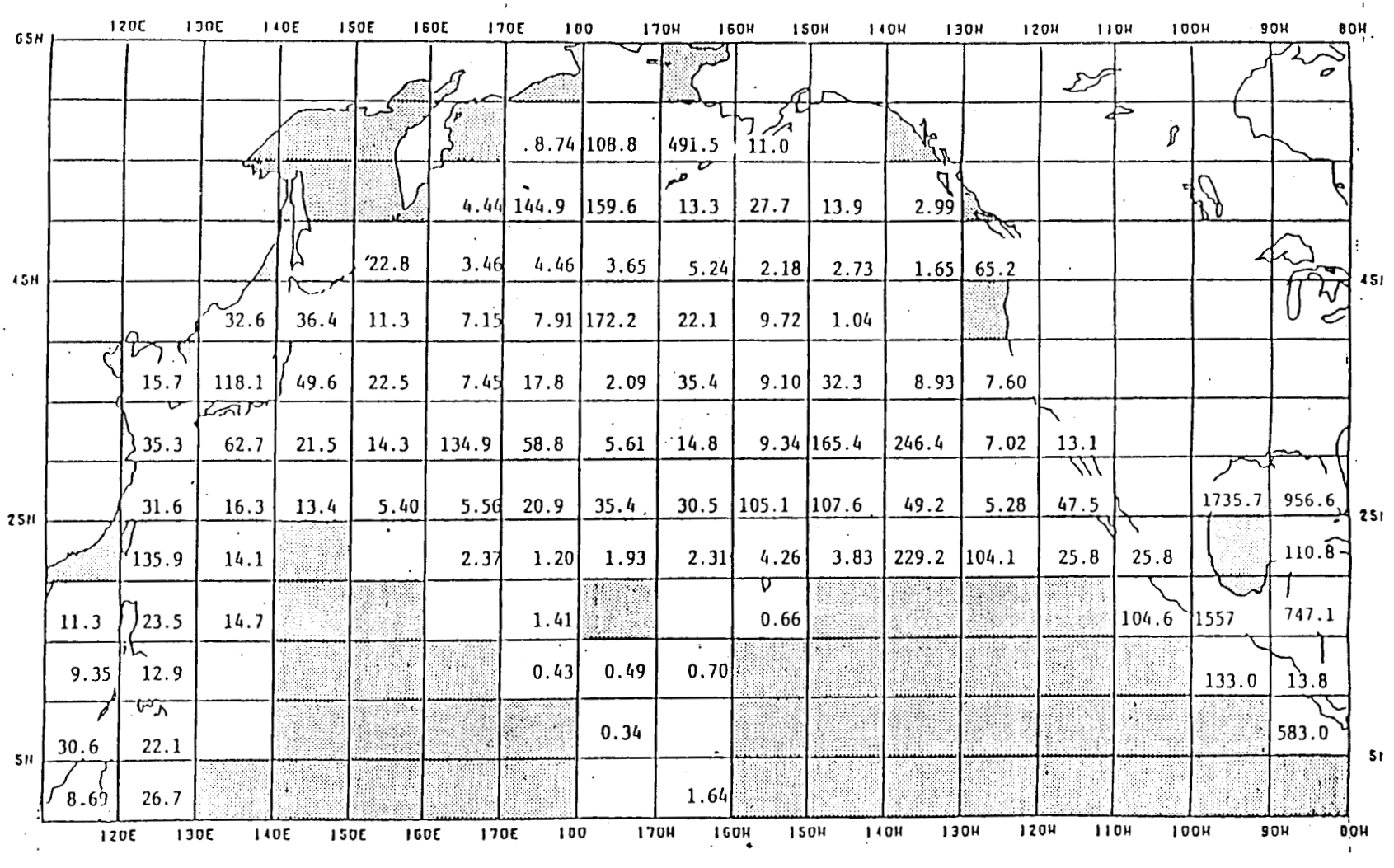

Figure 5J.--Estimated density distribution of total marine debris in 1987.
Unit: number of debris pieces $\times 10^{-1}$ per 1 nmi^2.

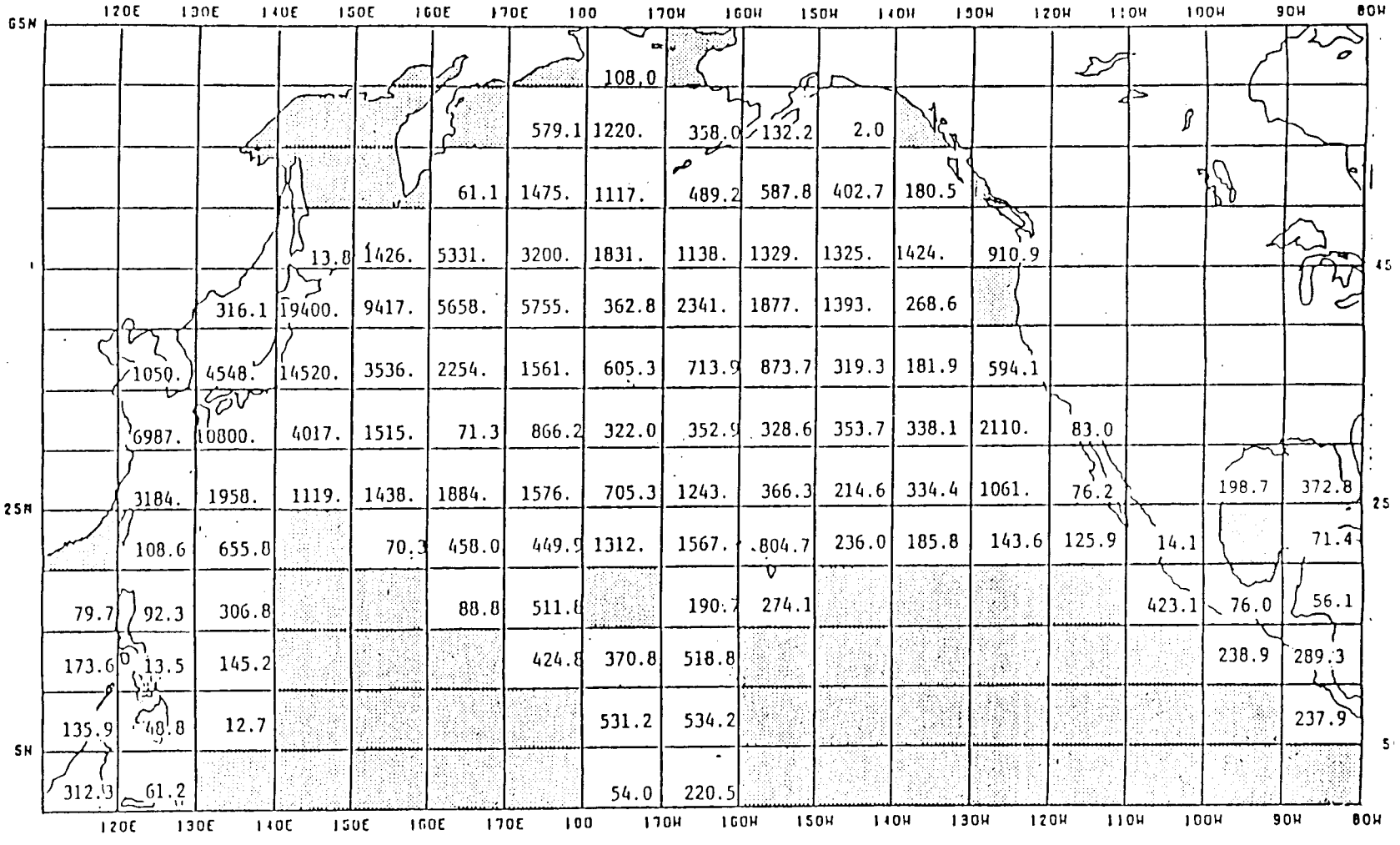

Figure 6.--Surveyed cruising distance in each 5° × 10° area in 1987. Unit: nautical mile.

fishing nets were not found at all. The distribution split to both south and north with this area in between, and it was thought that fishing nets found in the south were transported by currents moving from west to east. There were many unidentified fishing nets, and characteristics by kind of fishing net were not clearly recognizable. In waters north of lat. 50°N, only trawl nets were identified.

The numbers of other fishing gear sighted were greater than the number of fishing nets, and other fishing gear was found in 70.1% of all the areas surveyed. Although a distribution pattern of other fishing gear was similar to that of fishing nets, the blocks in which density was high inclined toward the south.

A great number of Styrofoam pieces were sighted. The range of distribution was widest, Styrofoam items being found in 77.8% of the blocks in the area surveyed. The distribution pattern was different for petrochemical articles other than Styrofoam, and the areas in which density was high were found in waters off Japan, at lat. 25° to 35°N and long. 170°W, lat. 25° to 35°N and long. 160°E to 140°W, in the Gulf of Mexico, and in the coastal areas of Central America. Areas which showed a comparatively high density were scattered widely. To explain the difference in this distribution pattern, petrochemical articles except Styrofoam are transported mainly by ocean currents, while Styrofoam items are floating on the surface of the sea and are thought to be strongly influenced by wind.

Other plastic debris was sighted in the greatest numbers (8,544 items), and the number of blocks sighted was the same as for other fishing gears. The distribution pattern was also similar. Six blocks in which the density was highest were concentrated in the range of lat. 20° to 35°N and long. 160°E to 130°W, followed by blocks in Japanese waters. In addition, an area in which the density was extremely high was in the Gulf of Mexico as well as the coastal areas of Central America.

For pieces of wood and drifting logs, densities were high in the coastal areas, suggesting that pieces of wood and drifting logs come primarily from the rivers and coastal areas. Floating seaweed showed this trend remarkably, and beyond three coastal blocks it was not found at all.

Blocks of highest density of combined petrochemical articles were seen in the coastal areas of Central America, followed by blocks of high density concentrated in waters of lat. 20° to 35°N and long. 150° to 130°W. Although the number of blocks was small, there were also those that showed high density in waters of lat. 25° to 35°N and long. 170°E to 170°W. Furthermore, densities of marine debris that were <2% of the highest density block, could be found in Japanese waters and the East China Sea, but a considerably high density was shown in the wide range. As another distinctive phenomenon, density was low in any blocks in waters of lat. 45° to 50°N, and the North Pacific Ocean and the Bering Sea are separated by this area. It is believed that marine debris seldom passes from one of these areas to the other.

Figures used in the above determinations were the numbers of individual items sighted. When considering the effects of marine debris,

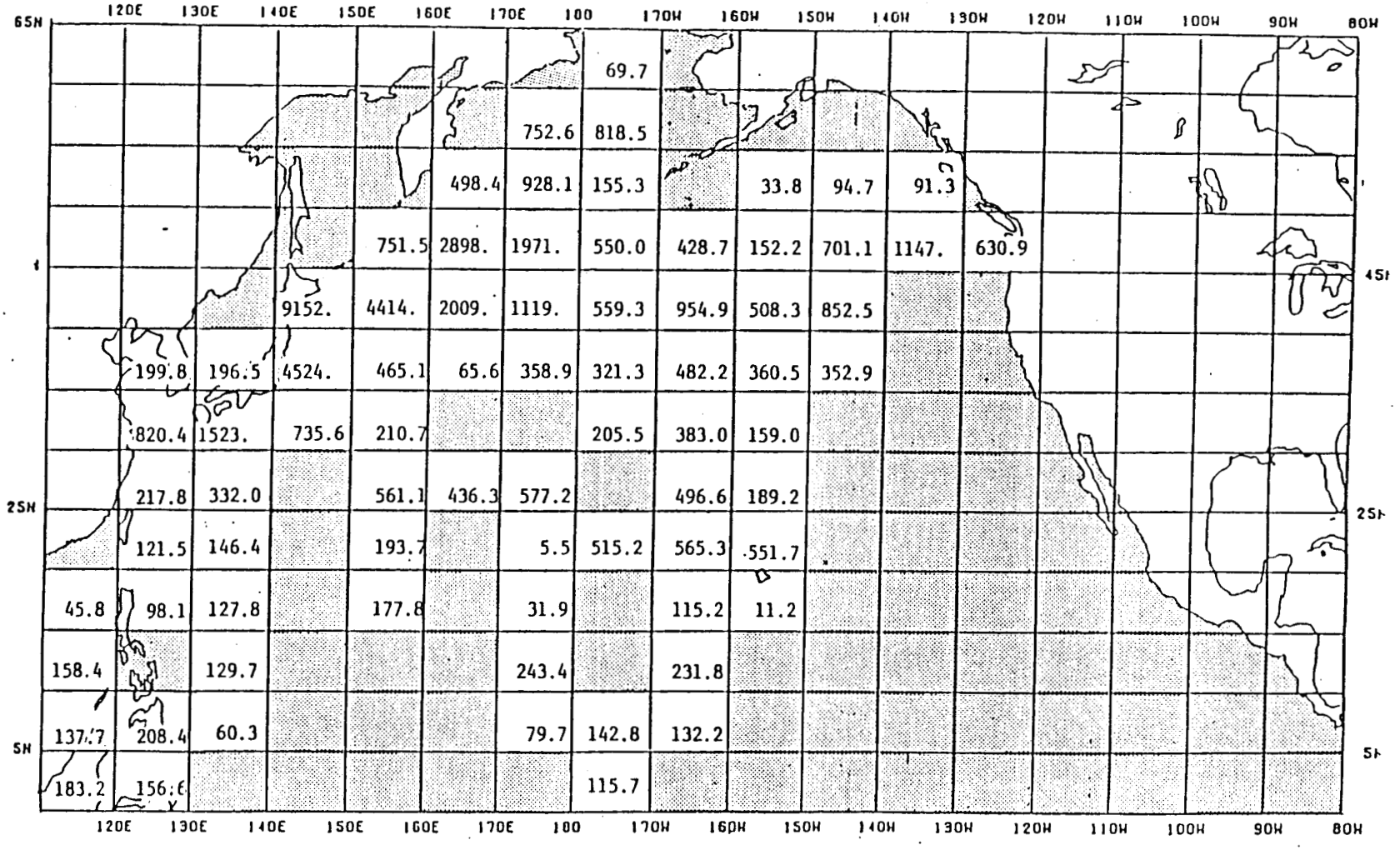

Figure 7.--Surveyed cruising distance in each 5° × 10° area in 1986. Unit: nautical mile.

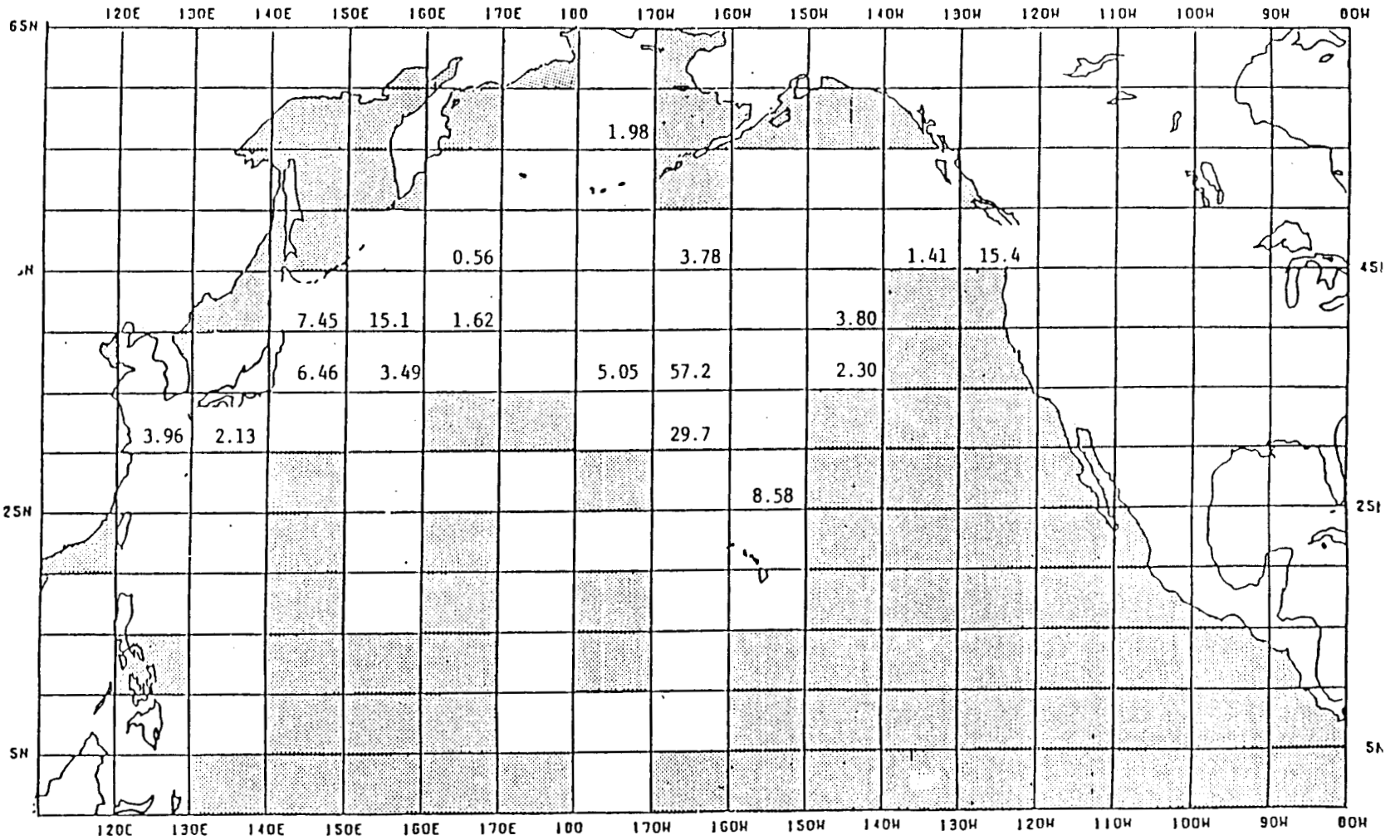

Figure 8A.--Estimated density distribution of fishing net debris in 1986. Unit: number of debris pieces × 10^{-1} per 1 nmi^2.

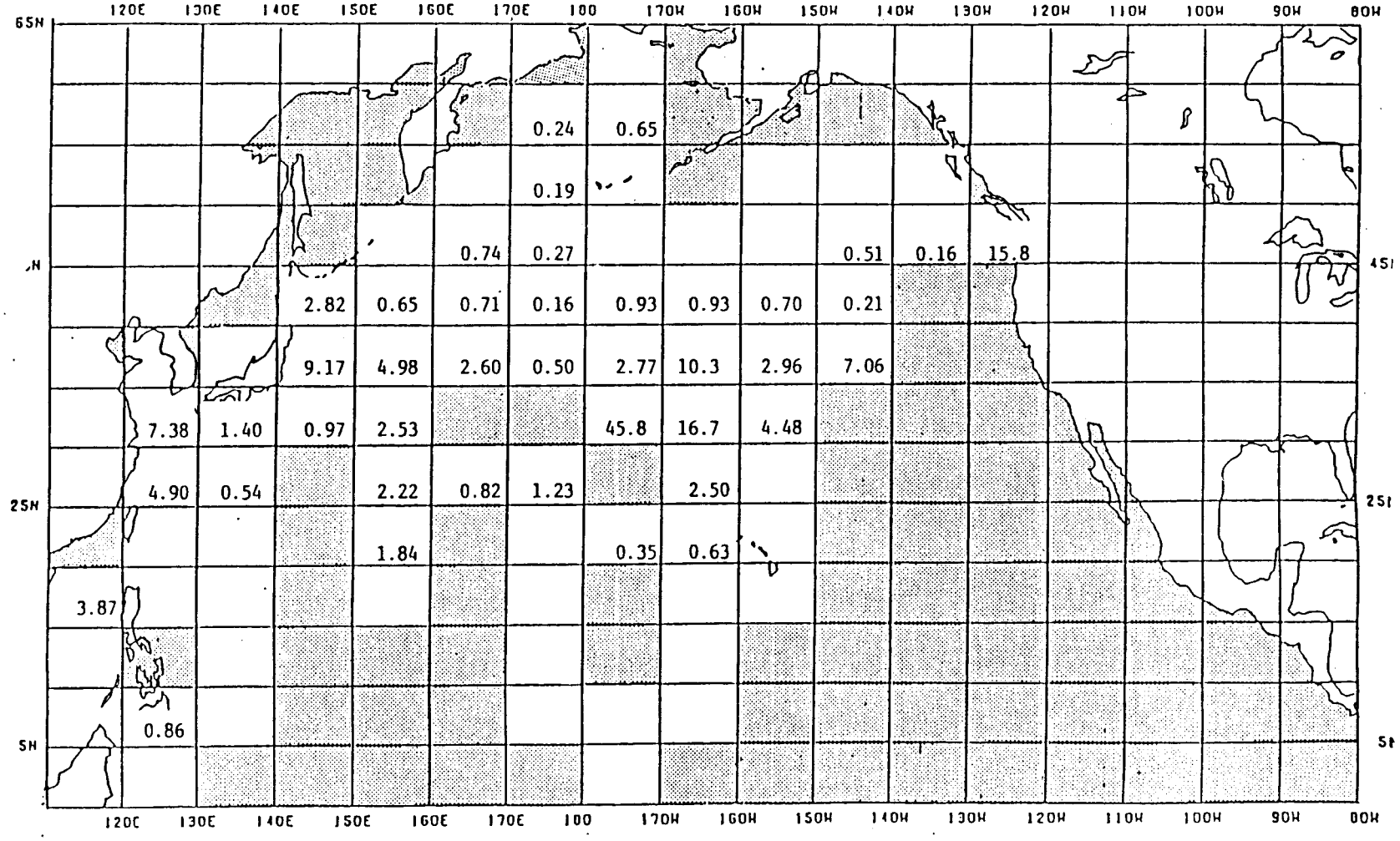

Figure 8B.--Estimated density distribution of other fishing gear debris in 1986. Unit: number of debris pieces × 10^{-1} per 1 nmi^2.

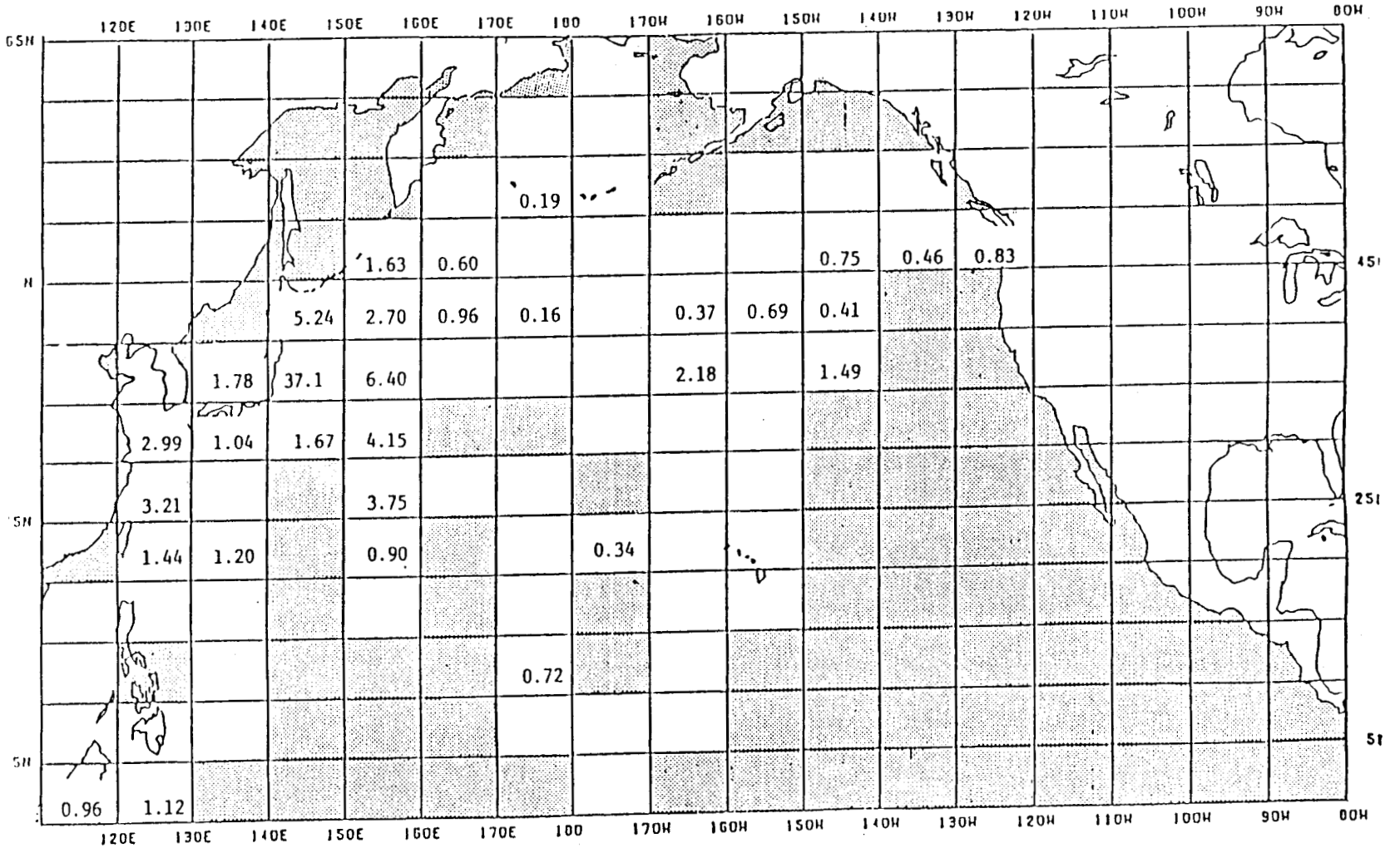

Figure 8C.--Estimated density distribution of Styrofoam debris in 1986.
Unit: number of debris pieces × 10^{-1} per 1 nmi^2.

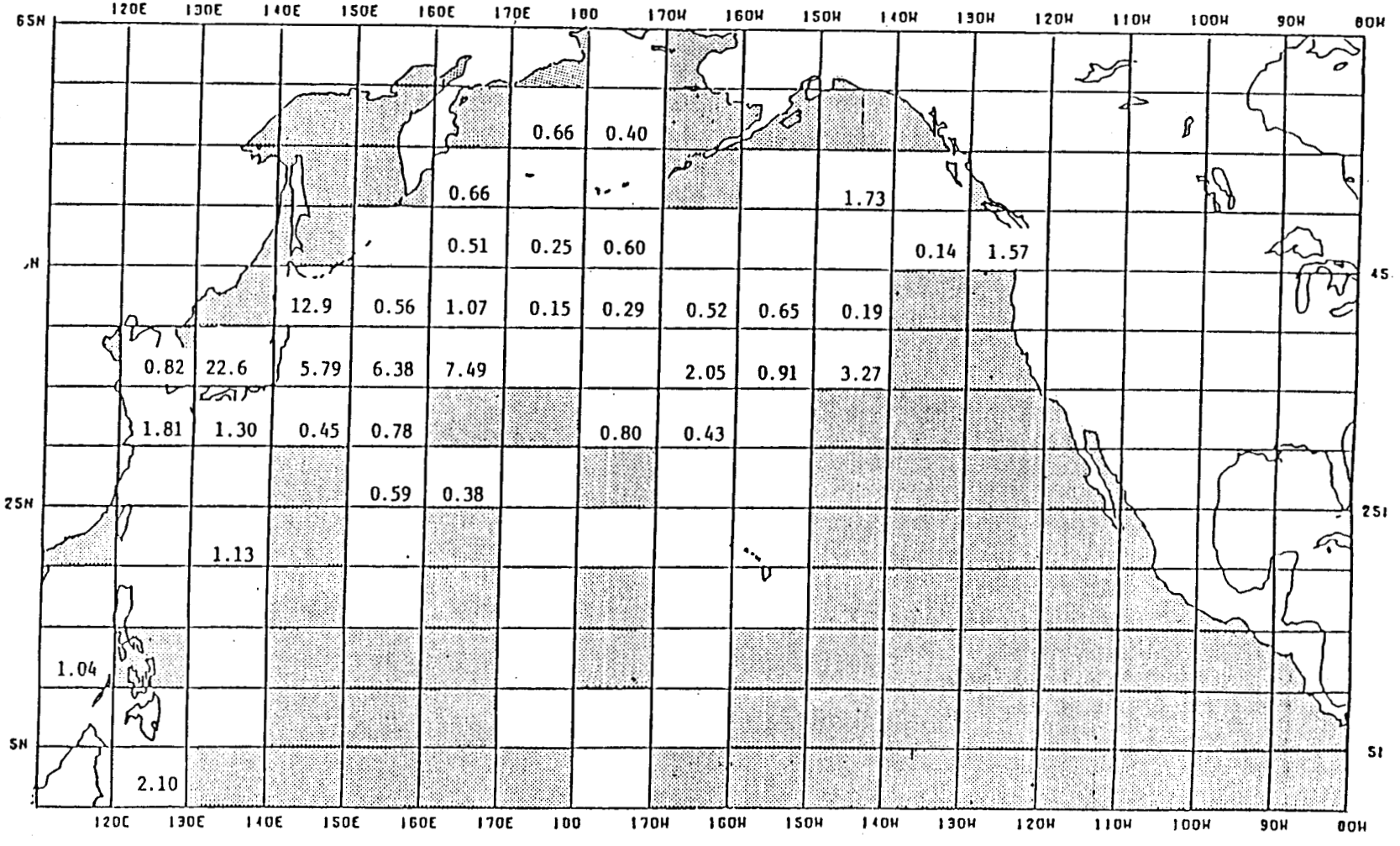

Figure 8D.--Estimated density distribution of other plastic debris in 1986. Unit: number of debris pieces $\times 10^{-1}$ per 1 nmi^2.

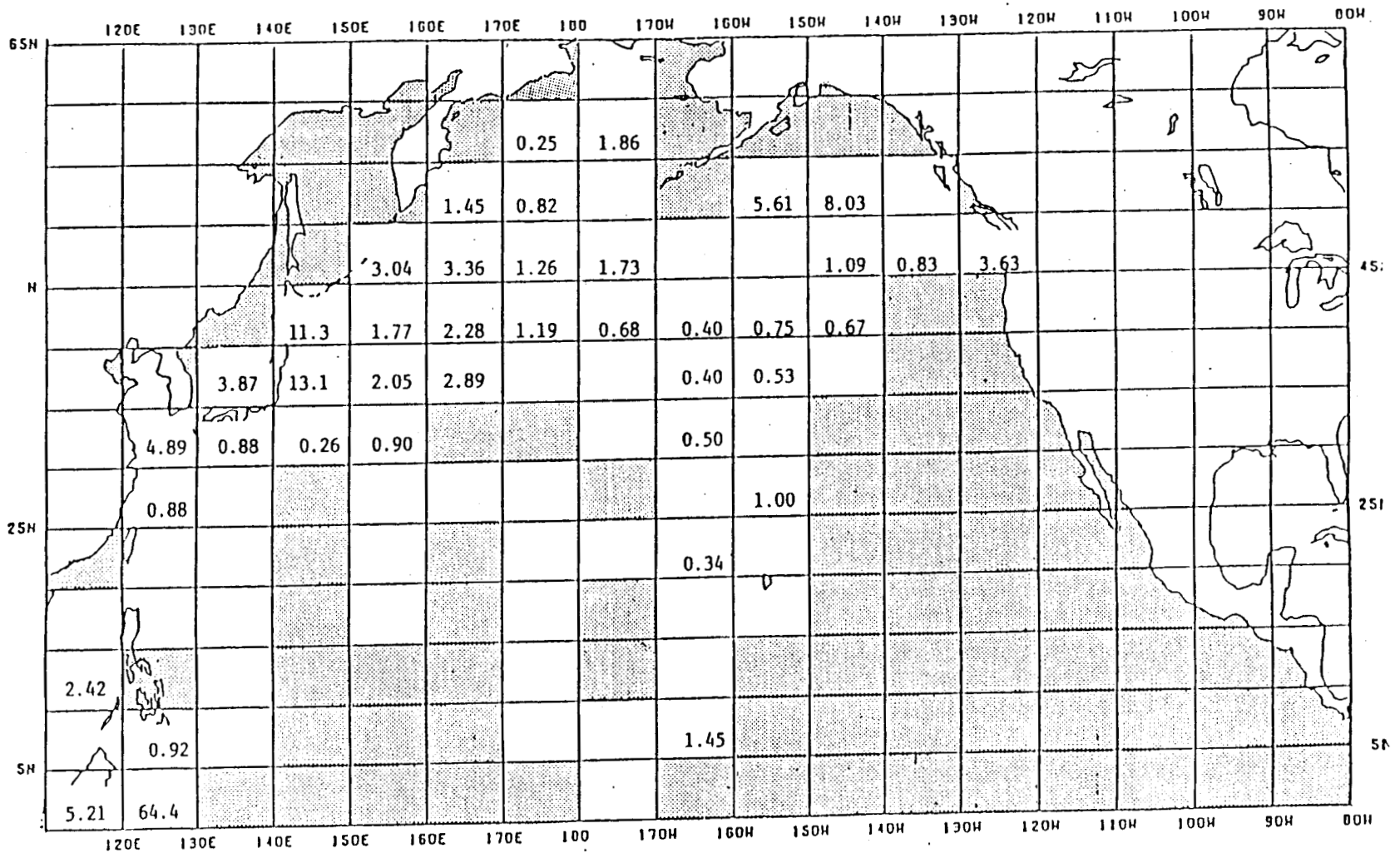

Figure 8E.--Estimated density distribution of wood debris in 1986.
Unit: number of debris pieces $\times 10^{-1}$ per 1 nmi^2.

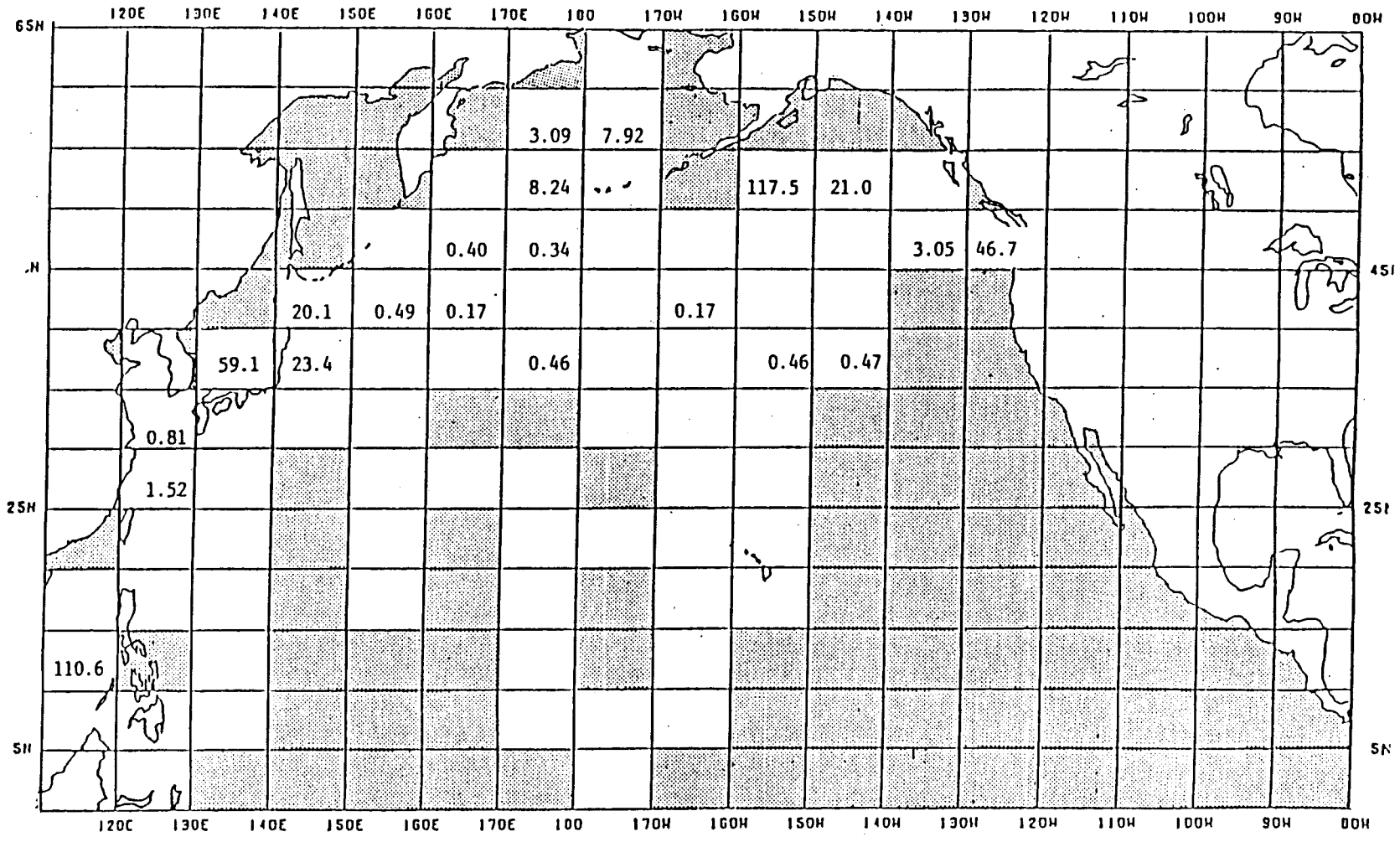

Figure 8F.--Estimated density distribution of floating seaweed debris in 1986. Unit: number of debris pieces × 10^{-1} per 1 nmi^2.

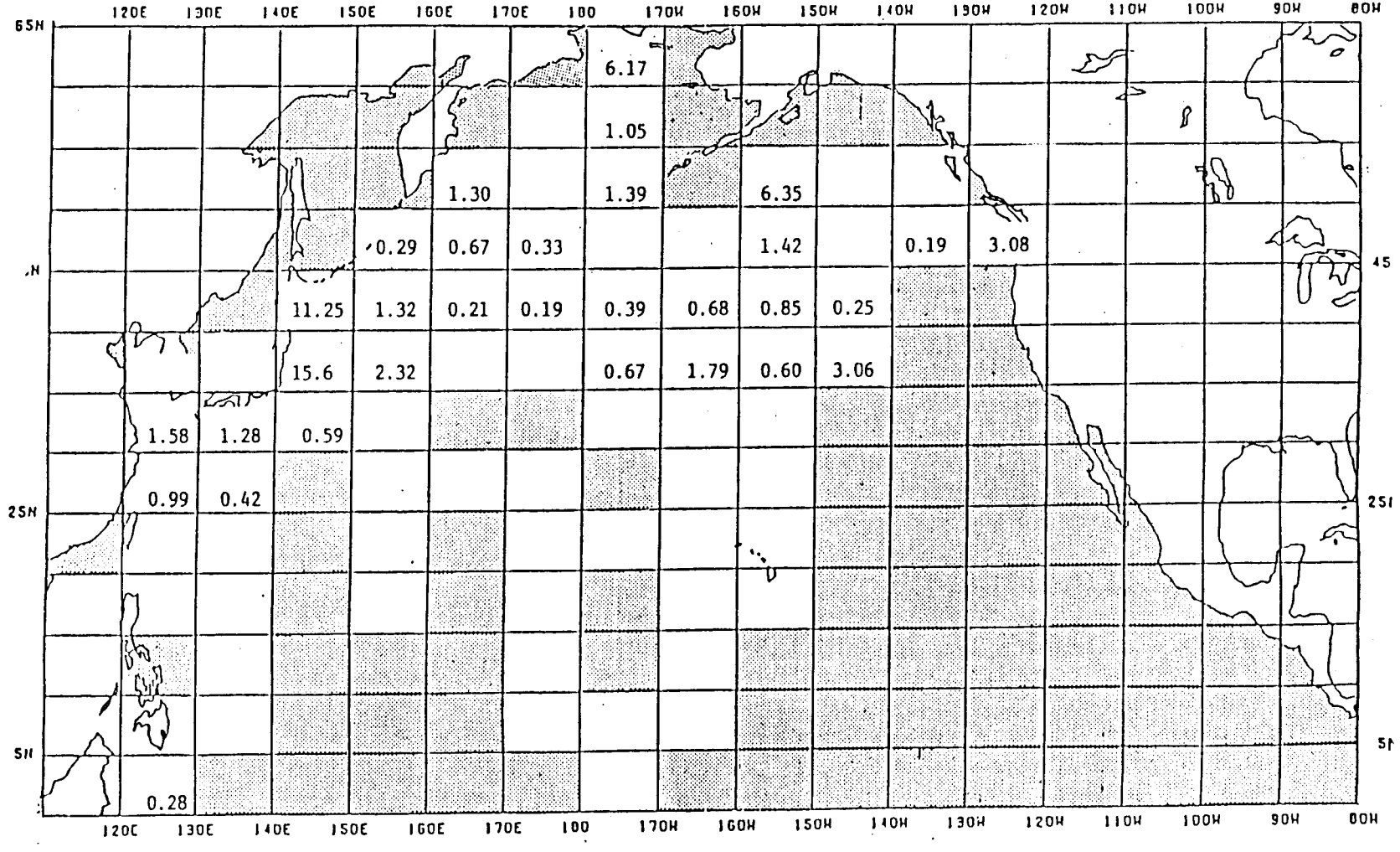

Figure 8G.--Estimated density distribution of other marine debris in 1986.
Unit: number of debris pieces × 10^{-1} per 1 nmi^2.

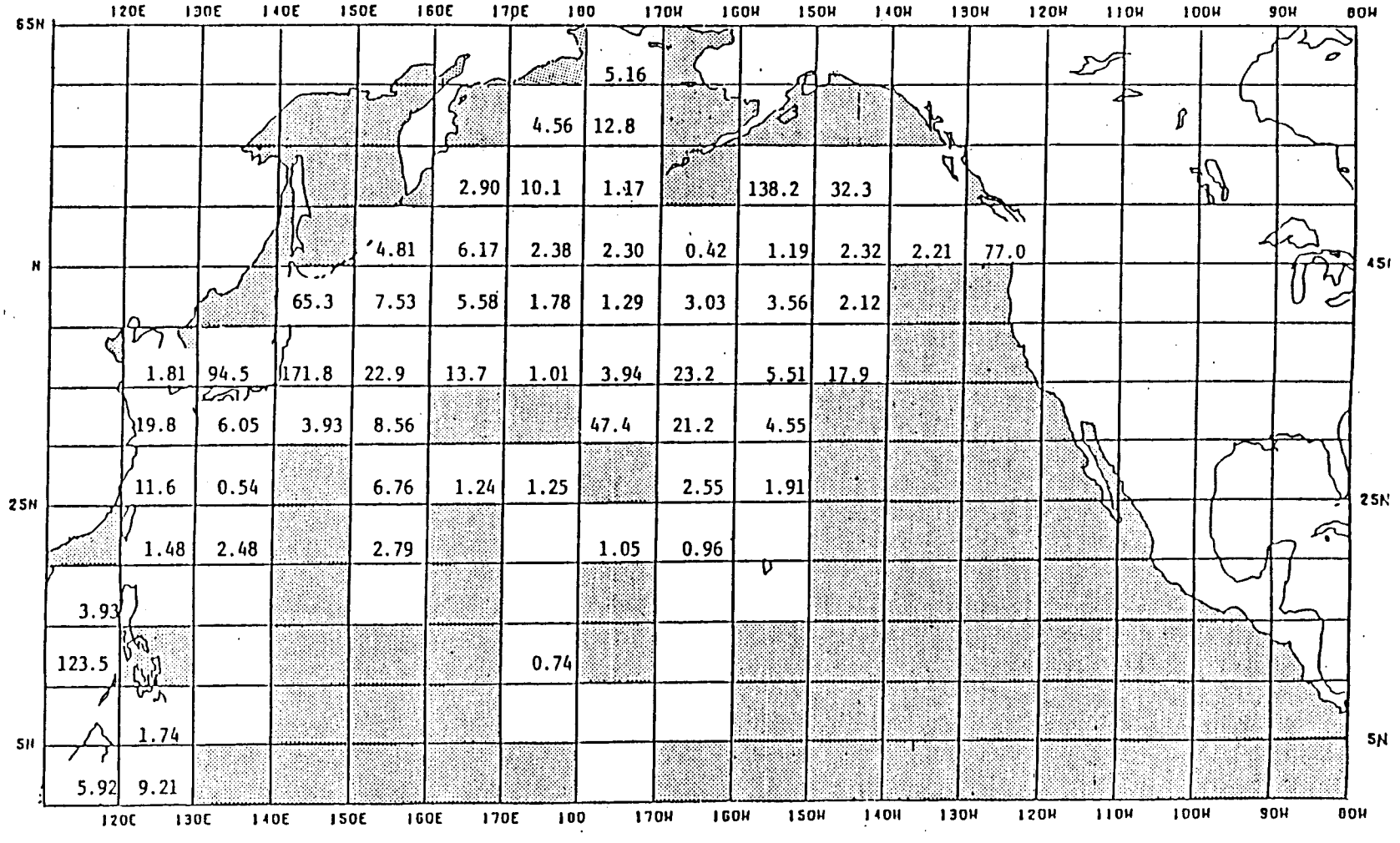

Figure 8H.--Estimated density distribution of total marine debris in 1986.
Unit: number of debris pieces × 10^{-1} per 1 nmi^2.

not only the number of individual items, but also their volume are important elements. However, it is quite difficult to measure with the eye the volume of things having various shapes. Therefore, in the survey we set these very rough size criteria and recorded the sizes of marine debris. Judging from the results by type of marine debris, "small" showed an extremely high rate, except in fishing net, pieces of wood, and drifting logs. In particular, "small" accounted for >90% of other plastic debris and Styrofoam, which were also great in actual volume. Although the number of items of this type of marine debris was great, it is believed that there was no greater difference in quantity than in number between this marine debris and other marine debris. More than half of the "large" items were fishing nets; the number was small, but the volume of each item was large. It is necessary to obtain more information on size in future surveys. It is believed that pieces of wood, drifting logs, and floating seaweed, which occur naturally, constitute the bulk of marine debris because of their large quantity and relatively large size.

These distribution patterns were almost the same as those obtained from the experimental sighting surveys conducted in 1986 (Figs. 7 and 8). It is necessary to study relationships between movement and accumulation of marine debris and ocean currents as well as to collect more data in the future. Furthermore, in order to understand yearly changes, it is also necessary to intensify the surveys in the North Pacific Ocean and adjacent areas and to establish methods of monitoring.

Yagi and Nomura (1988) reported on yearly changes in the density of marine debris based on sighting surveys conducted by the *Ryofu Maru* of the Meteorological Agency twice in winter and summer during 1976-86 using observations lines fixed between the Equator and lat. 34°N along long. 137°E. The survey results are said to be valuable for examining the yearly changes in marine debris using the same blocks at fixed periods each year, although observation blocks were limited in number. The survey results showed that the number of marine debris pieces sighted by unit distance more than doubled from when the survey was first launched. In particular, plastic sheet fragments have shown a marked increase in recent years.

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