Plastic Particles in Surface Waters of the Northwestern Atlantic

The abundance, distribution, source, and significance of various types of plastics are discussed.

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The occurrence of plastic particles has recently been reported in the Sargasso Sea (*1*) and in coastal waters of southern New England (*2, 3*). These reports were based on a small number of samples within limited geographic areas, but the observers suggested that plastics might be more widely distributed. We confirm, after examination of neuston (surface) net samples taken in July–August 1972, that plastic particles do occur over a wide area of the North Atlantic.

These samples were collected on the first multiship MARMAP (*4*) ichthyoplankton survey of coastal and oceanic waters from Cape Cod to the Caribbean. The three National Oceanic and Atmospheric Administration research vessels participating in this survey were the *Albatross IV, Delaware II*, and *Oregon II*. The plankton sampling locations for each vessel are shown in Fig. 1. The sampling gear (2 by 1 meter, rectangular-framed neuston net with 0.947-millimeter nylon mesh) and method of tow [10-minute surface tow at a speed of 5 knots (9.25 kilometers per hour)] were identical on each vessel. The plastic particles in each sample were manually sorted, enumerated by type, and their dry weight determined.

Plastic Types Collected

The types and characteristics of the plastic particles were as follows:

1) White opaque polystyrene spherules (*5*); mean diameter, 1.0 mm; range in diameter, 0.2 to 1.7 mm; mean weight, 0.0007 g; range in weight, 0.0001 to 0.00023 g; mean density, 1.023 g/cm^3; range in density, 1.010 to 1.047 g/cm^3 (Fig. 2A).

2) Translucent to clear polystyrene spherules containing gaseous voids (*5*); mean diameter, 1.5 mm; range in diameter, 0.9 to 2.5 mm; mean weight, 0.0014 g; range in weight, 0.0004 to 0.0039 g; density, < 1.000 g/cm^3 (Fig. 2B).

3) Opaque to translucent polyethylene cylinders or disks (*5*); mean diameter, 3.4 mm; range in diameter, 1.7 to 4.9 mm; mean thickness, 2.0 mm; range in thickness, 1.1 to 3.4 mm; mean weight, 0.0138 g; range in weight, 0.0106 to 0.0250 g; density, < 1.000 g/cm^3 (Fig. 2C).

4) Pieces of Styrofoam (Fig. 2D).

5) Sheets of thin, flexible wrapping material (Fig. 2E).

6) Pieces of hard and soft, clear and opaque plastics of various thicknesses which appear to be parts of plastic containers, toys, and so forth (Fig. 2F).

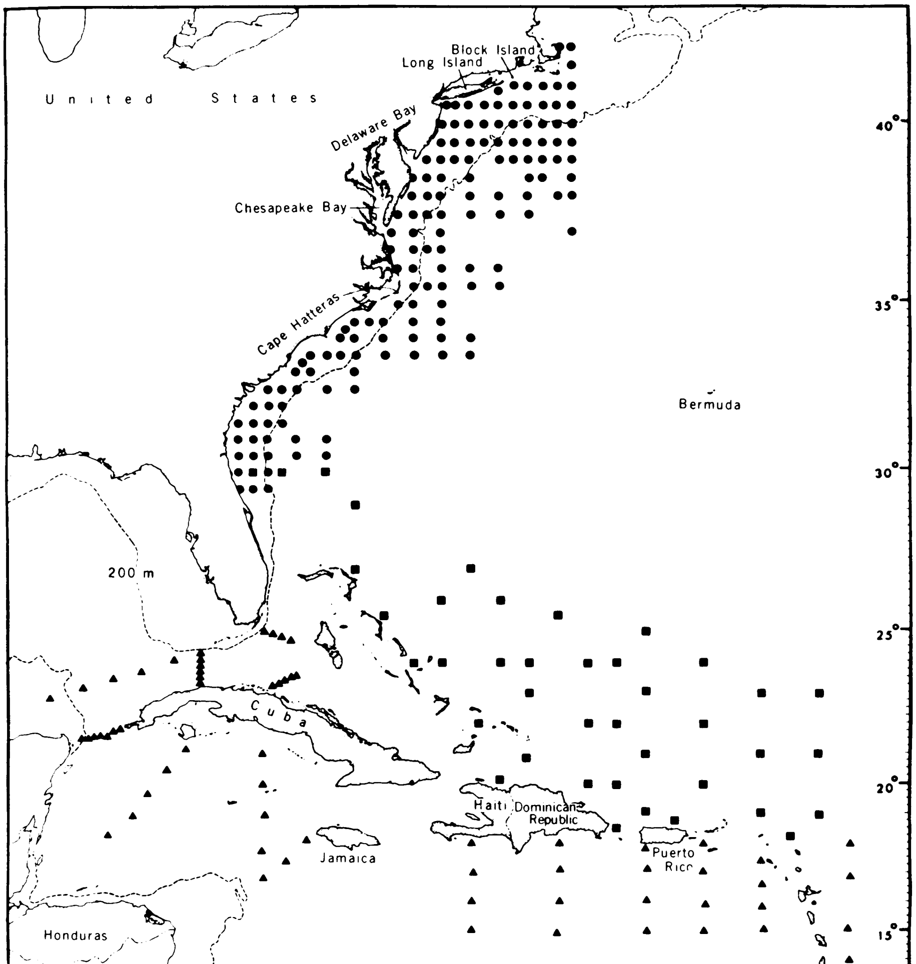

Fig. 1. Neuston net sampling locations: ■, *Albatross IV* cruise 72-6, 11 July–16 August 1972; ●, *Delaware II* cruise 72-19, 12 July–13 August 1972; ▲, *Oregon II* cruise 39, 13 July–8 August 1972.

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Sampling Bias

Under normal towing conditions (that is, with the net meshes not clogged) appreciable numbers of particles smaller than 1.0 mm in diameter pass through the mesh (0.947-mm aperture) of the neuston net. In addition, at a speed of 5 knots some particles larger than 1.0 mm in diameter are forced through the meshes. The possible loss of smaller particles is supported by the fact that the mean diameter (0.5 mm) of the polystyrene spherules collected in southern New England coastal waters by Carpenter *et al.* (*2*), using 0.333-mm mesh nets, was appreciably less than the mean diameter (1.3 mm) of similar polystyrene spherules in the *Delaware II* samples. The polystyrene spherules in our samples appear identical to the polystyrene "suspension beads" that are shipped to plastic fabricators by polystyrene producers. The mean diameter of a manufacturer's sample (*6*) of these suspension beads was 0.5 mm. The beads ranged in diameter from 0.2 to 1.6 mm.

Many of the opaque polystyrene spherules collected were of greater density than seawater, as were the opaque polystyrene suspension beads obtained from the plastic producers. These spherules, which could only be maintained in the surface layers in areas of strong vertical mixing, were less abundant in terms of both number and weight than the less dense, clear polystyrene spherules (Table 1). Obviously, these opaque spherules and other plastic particles of similar density must also occur in subsurface waters. Evidence for this is the occurrence of opaque spherules in subsurface waters of Block Island Sound (*3*), in bottom sediments off New Haven, Connecticut (*7*), and in the Connecticut River (*8*). Thus, because a proportion of plastic particles was not in the surface layer and because smaller particles were not fully retained by the 0.947-mm mesh, the values presented here underestimate the number of particles under a unit area of sea surface.

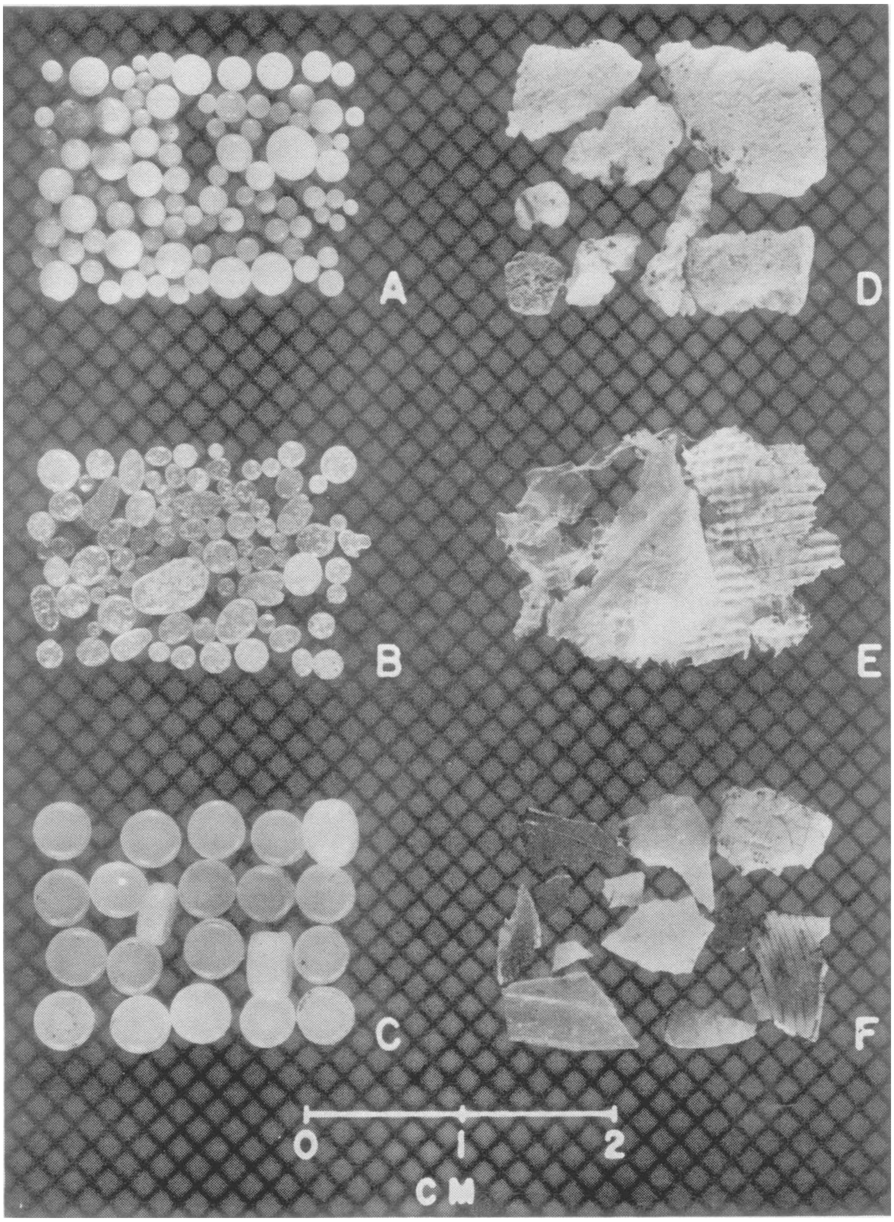

Fig. 2. Typical plastic particles: (A) opaque polystyrene spherules, (B) clear and translucent polystyrene spherules, (C) opaque and translucent polyethylene cylinders, (D) Styrofoam, (E) plastic sheets, and (F) plastic pieces.

Abundance and Distribution of Plastics

Fifty percent of the *Oregon II* samples collected in the Caribbean Sea, 57 percent of the *Albatross IV* samples collected in the Antilles Current area, and 69 percent of the *Delaware II* samples collected in coastal, Slope, and Gulf Stream waters between Florida and Cape Cod contained plastics. The composition of the plastic particles and their abundance in terms of both number and weight varied with geographic area (Table 1). The opaque and clear polystyrene spherules occurred only in samples collected in waters north of Florida (*Delaware II*). The abundance of all plastic types was greatest in waters north of Florida and least in the Caribbean Sea. The ratio of the mean weight of all plastics from *Delaware II*, *Albatross IV*, and *Oregon II* samples was 8 : 2 : 1.

The distribution of opaque polystyrene spherules was restricted to the area north of latitude 37°N (Fig. 3). The greatest concentration of these particles was in coastal waters south of Rhode Island and south of eastern Long Island. A secondary concentration occurred approximately 110 kilometers southeast of Delaware Bay. It was only off southern New England and Long Island that these particles were found at stations immediately adjacent to the coast.

Transparent polystyrene spherules were found over a slightly more extensive area than the opaque spherules (Fig. 3). With the exception of one spherule found well east of the main axis of the Gulf Stream at 34°N, the clear spherules were restricted to the area north of 36°N. As in the case of the opaque spherules, the most extensive concentration of clear spherules occurred in coastal waters south of Rhode Island and south of eastern Long Island with a more limited concentration centered approximately 110 km southeast of Delaware Bay. Only off southern New England and Long Island were these particles found at the most inshore stations.

The most extensive concentration of polyethylene cylinders occurred in continental shelf waters off southern New England and eastern Long Island, and off the coast of southern New Jersey and Delaware (Fig. 4). More limited concentrations were found in and to the east of the Gulf Stream, just south of Cape Hatteras, and in the Yucatan Channel. These particles were also collected in limited numbers at scattered stations throughout the Antilles Current area and at two stations in the Caribbean Sea. No particles were found at stations in the Straits of Florida, in the southeastern Gulf of Mexico, or in coastal and Gulf Stream waters south of Cape Lookout, North Carolina. The polyethylene cylinders occurred at stations immediately adjacent to the coast off southern New England and eastern Long Island, at one station southeast of Ocean City, Maryland (38°N), at one station off the south coast of Puerto Rico, and at one station off the north coast of Cuba. In addition to these col-

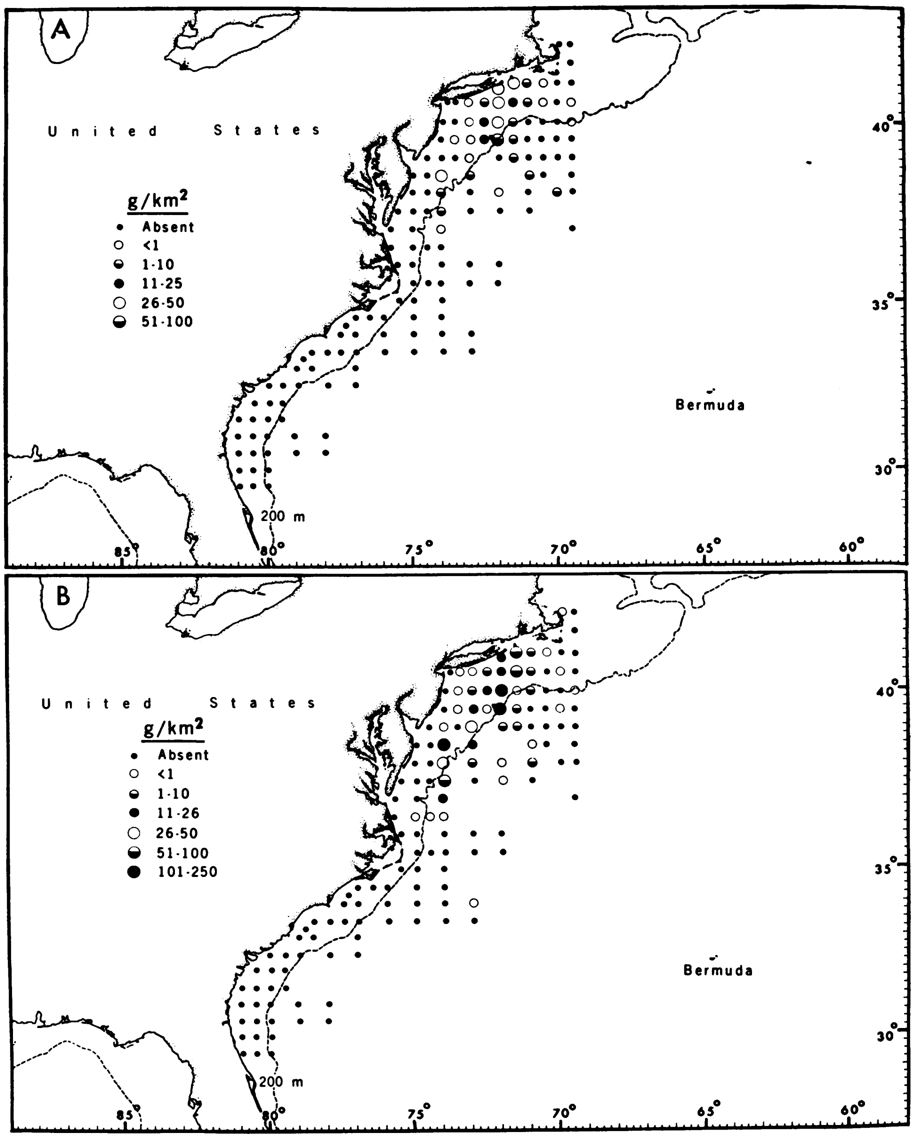

Fig. 3. Distribution of opaque (A) and clear (B) polystyrene spherules.

Table 1. Mean abundance and maximum abundance of plastic particles. The numbers of Styrofoam pieces and plastic sheets and pieces are not listed because of appreciable variations in the sizes of these particles between stations.

Plastic type	Mean (total stations)				Maximum (positive stations)			
	Number per tow	Grams per tow	Number per square kilometer	Grams per square kilometer	Number of tows	Number per tow	Number per square kilometer	Grams per square kilometer
			Oregon II (*64 stations*)					
Opaque spherules	0							
Transparent spherules	0							
Opaque cylinders	0.2	0.004	60.6	1.4	6	4	1,292	32.1
Styrofoam		0.0002		0.1	2			0.3
Sheets and pieces		0.028		9.0	31			222.1
Total		0.032		10.5				
			Albatross IV (*40 stations*)					
Opaque spherules	0							
Transparent spherules	0							
Opaque cylinders	0.5	0.007	148.4	2.2	8	9	2,707	37.6
Styrofoam		0.002		0.7	7			17.5
Sheets and pieces		0.047		15.2	22			214.9
Total		0.056		18.1				
			Delaware II (*143 stations*)					
Opaque spherules	6.2	0.007	1996.4	2.3	31	188	60,724	53.0
Transparent spherules	16.9	0.019	5465.7	6.4	43	517	166,991	237.6
Opaque cylinders	2.7	0.034	855.4	11.2	40	107	34,561	406.1
Styrofoam		0.021		6.9	17			721.9
Sheets and pieces		0.158		50.9	98			1,403.5
Total		0.239		77.7				

lections at sea, polyethylene cylinders have been found in appreciable numbers on a beach at Barranquilla, Colombia (*9*), on Padre Island Beach near Corpus Christi, Texas (*10*), on Kalaloch Beach, Washington (*11*), and in bird gizzards on Amchitka Island in the Aleutian chain (*12*).

Pieces of Styrofoam were concentrated in only two relatively small areas, one in coastal waters off eastern Long Island and the other centered approximately 130 km east-southeast of Delaware Bay (Fig. 5). In all other areas Styrofoam particles occurred in isolated patches. Styrofoam was collected at only one station in the Caribbean Sea. At only two locations, eastern Long Island and Cape Cod, were Styrofoam particles found at stations immediately adjacent to the coast.

Plastic sheets and pieces were not only the most abundant particle types collected but also the most widely dispersed (Fig. 6). The greatest concentrations of these particles were found in continental shelf waters between Virginia (37°N) and Rhode Island (41°N). The sheets and pieces were the only types of plastics found in appreciable numbers in continental shelf waters south of Cape Hatteras and the only types found in the majority of stations in the Caribbean Sea and Antilles Current area. A band approximately 110 km wide and extending approximately 289 km offshore separated the concentration of plastic sheets and pieces north and south of Cape Hatteras. This band coincides with the area between the offing of Chesapeake Bay and Cape Hatteras in which there is a marked offshore component of surface drift.

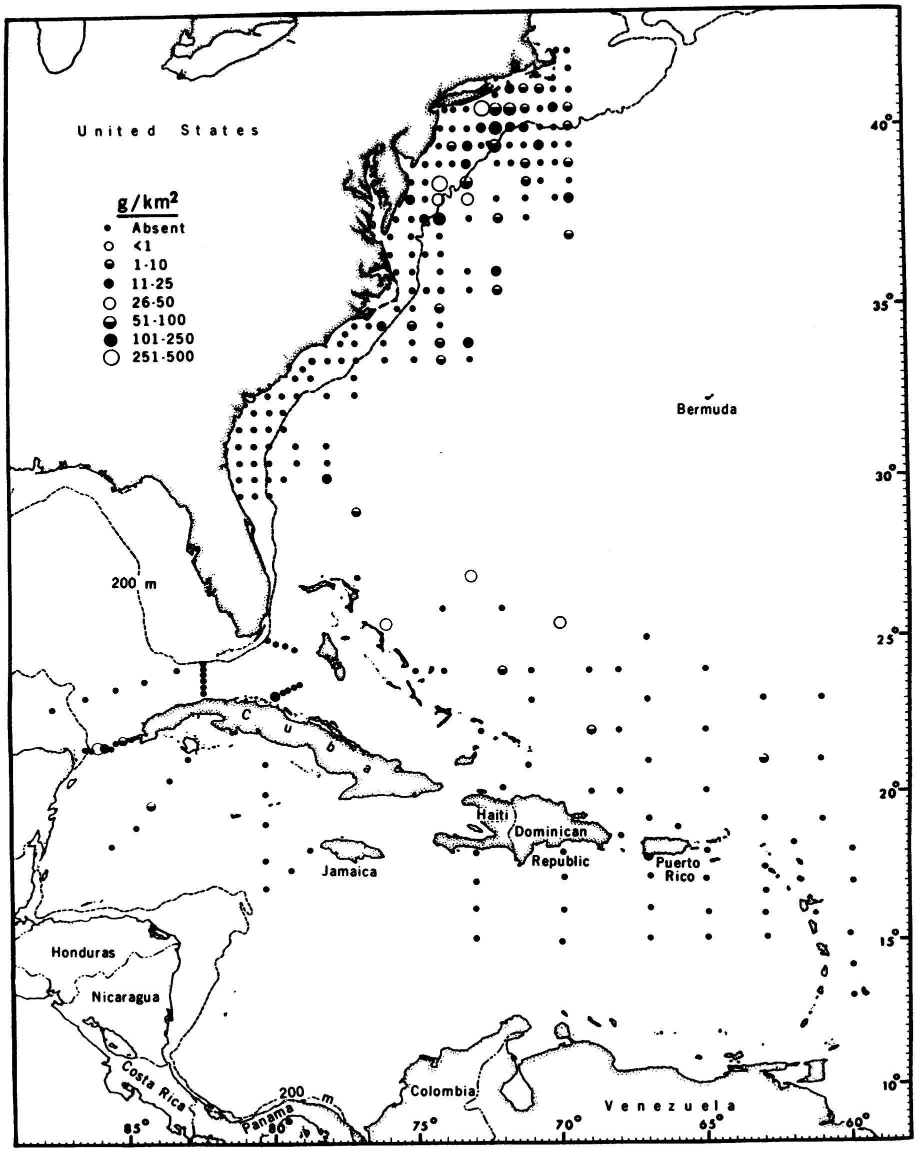

Fig. 4. Distribution of polyethylene cylinders.

Sources of Plastics

There would appear to be only three possible major sources of Styrofoam and pieces and sheets of formulated and compounded plastics (wrapping material, containers, toys, and so forth): (i) municipal solid waste disposal at sea, (ii) coastal landfill operations, and (iii) disposal at sea of solid waste generated by individual vessels. There is no appreciable refuse or garbage dumping in U.S. Atlantic coastal waters (*13*). The fact that in most areas the maximum concentrations of formulated and compounded plastics were well offshore rather than immediately adjacent to the coast indicates that landfill operations are not a major source of these particles. In view of the above, our personal experience at sea aboard research and commercial vessels, and the superposition of areas of high particle abundance and maximum vessel activity, we have concluded that the accumulation of compounded plastics in the sea surface results from routine at-sea solid waste disposal by individual vessels. The bulk of this solid waste consists of material used to package food and other products.

The only apparent way in which the clear and opaque polystyrene spherules enter the ocean is via waste-water discharge from a plastic-producing or plastic-processing plant into a river or estuary. Most of the plastic-producing and plastic-processing companies along the East Coast of the United States are located in southern New England and in the Middle Atlantic states, and the majority of the polystyrene producers are located in Connecticut, New York, and New Jersey (*14*).

A study was made by the Society of the Plastics Industry, Inc., in 1972 of waste emission practices of plants producing polystyrene resins on the East Coast of the United States. This study was prompted by the discovery by Carpenter *et al.* (*2*) of plastic spherules in southern New England coastal waters. The society concluded at that time that only one of these plants was following procedures that occasionally emitted particles via a waste-water system that emptied into a river flowing into the Atlantic (*15*). A more recent study by Hays and Cormons (*16*) however, disclosed the presence of opaque polystyrene spherules in the sand and leaf litter near the sewage outlet of a plastic manufacturing plant on the Chicopee River, Massachusetts, and in mud at the mouth of the Connecticut River at Saybrook.

The distribution of both clear and opaque polystyrene spherules (Fig. 3) indicates that the majority of these particles enter open coastal waters in the area between Block Island and the eastern tip of Long Island. The occurrence of polystyrene particles in plankton samples collected in eastern Long Island Sound and Block Island Sound is now commonplace. The distribution of particles in Long Island Sound and Block Island Sound (*2, 3, 17*) indicates that the bulk of these particles is introduced along the coast of Connecticut between longitudes 72°W and 73°W. The Connecticut, Niantic, Thames, and numerous smaller rivers drain into this area. Polystyrene spherules have been found in Niantic Bay (*2*) and in the Connecticut River as far north as Massachusetts (*18*).

Observations of currents, particularly in the eastern part of Long Island Sound, show that the ebb tide is stronger than the flood tide at the surface layer, whereas the reverse is true at the bottom. Thus there is a tendency here, as in many sounds and estuaries, for the surface layer to move seaward and to be replaced by saline water flowing in along the bottom (*19*). This seaward flow of surface water out of Long Island Sound in the area between Montauk Point and Block Island (*20*) is augmented by river drainage, three-quarters of which enters the relatively open eastern end of Long Island Sound where it is flushed out rapidly.

The surface outflow of well-mixed, river-freshened water out of Block Island Sound which then spreads seaward in a southwesterly direction has been discussed and illustrated by Miller (*21*) and Bumpus (*22*). There is a general southerly surface drift over much of the Middle Atlantic Bight culminating in a seaward outflow in the area between Chesapeake Bay and Cape Hatteras. The distribution of clear and opaque polystyrene spherules in coastal waters is in accord with coastal surface circulation, as inferred from drift bottle studies (*21, 22*) and the distribution of temperature and salinity (*21*).

The polyethylene cylinders are called "nibs" in the chemical trade and, as in the case of the polyethylene "suspension beads," are a bulk material used in fabricating plastic products. It is apparent that the sources of these particles are plastic-producing and plastic-processing plants, because these cylinders have been found at waste-water outlets of plastic manufacturing plants in Massachusetts, Connecticut, and New Jersey, and in streams just below plants in New York and New Jersey (*16*).

Polyethylene cylinders have been collected in appreciable numbers in Block Island Sound (*3*). We have received no reports of their being found in the waters of Long Island Sound, although they have been found on the shore at Saybrook, Connecticut, and Fire Island, New York (*16*). The distribution of these cylinders (Fig. 4) indicates that, although the bulk of these particles enter open coastal waters in the area between Block Island and Long Island, a significant number of these particles enter coastal waters via Delaware Bay. The distribution of these particles off southern New England and eastern Long Island and off the coast of southern New Jersey and Delaware is in accord with the offshore component of drift, as indicated by the paucity of onshore drift bottle recoveries in both eastern Long Island and in the vicinity of Delaware Bay (*21*).

The fact that polyethylene cylinders were also found in oceanic waters south of Cape Hatteras, in the Yucatan Channel, at scattered stations both north and south of the Greater Antilles, and on beaches at Barranquilla, Colombia; Corpus Christi, Texas; Kalaloch, Washington; and in the Aleutian Islands, implies that there are additional sources of these particles. Supporting evidence for this is the fact that the polyethylene cylinders collected in the Caribbean Sea and on the beach at Barranquilla were appreciably longer and heavier than the more disk-like particles collected by the *Albatross IV* and *Delaware II*. The average weight

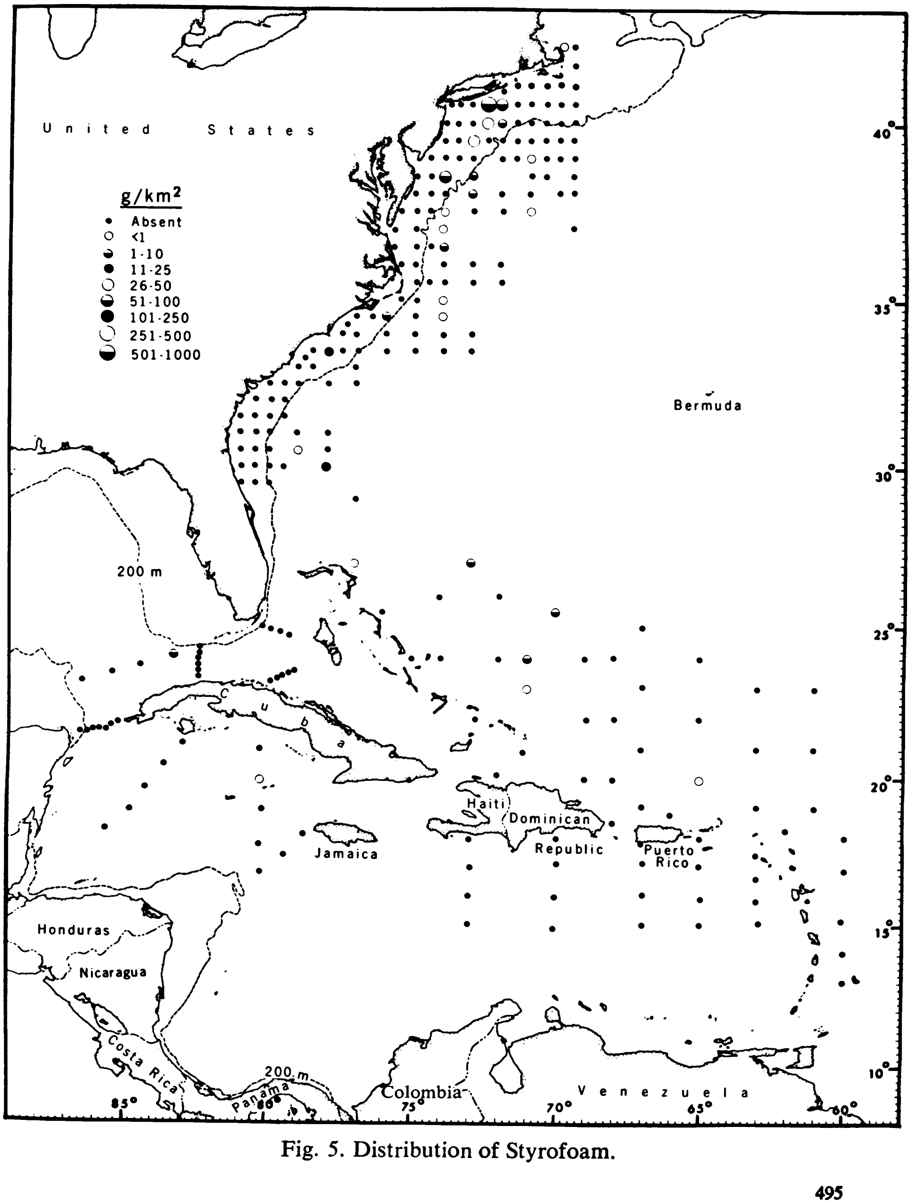

Fig. 5. Distribution of Styrofoam.

of *Oregon II* particles was 0.0228 g, whereas the average weights of *Albatross IV* and *Delaware II* particles were 0.0149 and 0.0130 g, respectively. In addition, the *Oregon II* and Barranquilla beach particles were less weathered and less brittle and had sharper edges and cleaner surfaces than the *Albatross IV* and *Delaware II* particles, all of which indicates more recent introductions into the sea.

Environmental Effects

The main danger to marine life and human health comes from wastes that are highly toxic or exceptionally long lasting. As far as we know, the plastics we are concerned with here are not toxic. But, they are also not biodegradable. Once they are introduced into the marine environment, they remain indefinitely even though they gradually break up into smaller particles.

The plastic particles do act as surfaces for the growth of hydroids, diatoms, and bacteria (*1*) and possibly for the accumulation of polychlorinated biphenyls (PCB's) from ambient seawater (*2*). White polystyrene spherules have been found in the stomachs of a number of species of larval and juvenile fishes both in Niantic Bay (*2*) and in the Connecticut River (*23*). They also have been found in the stomach contents of flounders (*Platichthys flesus*) (2 to 5 centimeters) in Severn Estuary, United Kingdom (*24*), and in tern and gull pellets on Great Gull Island, New York (*16*). Carpenter *et al.* (*2*) have suggested that the ingestion of plastic may lead to intestinal blockage and possible mortality in smaller larval fishes.

We found no plastic particles in the gut contents of over 500 larval and juvenile fishes (22 species) collected in the areas of maximum abundance of opaque spherules. Experiments were conducted to determine if larval and juvenile fishes maintained in 15-gallon (0.04-cubic-meter) laboratory aquariums would feed on plastic spherules, and if so, to determine the effect of ingestion. Polystyrene and acrylonitrile-butadiene-styrene suspension beads (5 g each, approximately 43,500 particles) were added to each aquarium. Juvenile striped killifish (*Fundulus majalia*), juvenile tomcod (*Microgadus tomcod*), juvenile three-spined stickleback (*Gasterosteus aculeatus*), juvenile winter flounder (*Pseudopleuronectes americanus*), larval haddock (*Melanogrammus aeglefinus*), and larval winter flounder were used in these experiments. The juvenile fishes were fed chopped squid twice weekly, and the larvae were fed fresh net plankton daily. The larvae ranged in length from 4.2 to 6.0 mm and the juveniles from 15 to 50 mm.

The larvae were maintained for 2 weeks until a cooling system breakdown caused total mortality. No spherules were found in the digestive tracts of larvae killed and examined daily during this period. The juvenile fishes experienced less than 2 percent mortality during an 8-week period. This mortality was due to fungal infection. Samples of juvenile fishes were killed weekly, and, as with the larvae, no spherules were found in the gut contents. Juvenile killifish and tomcod were observed to take spherules, but in most cases they were immediately rejected. Any plastics that were swallowed apparently passed through the gut with no ill effects.

At the present levels of abundance of plastic particles in coastal and oceanic waters, adverse biological consequences would appear to be minor compared to the deleterious effect of other contaminants such as petroleum residues and other chemical wastes. Increasing production of plastics, combined with present waste disposal practices, will undoubtedly lead to increases in the concentration of these particles in rivers, estuaries, and the open ocean. The U.S. production of synthetic resins for plastic uses (excluding textile products) was about 20 $\times$ 10^9 pounds (9 $\times$ 10^6 metric tons) in 1972 (*25*). This quantity of resin is combined with about an equal weight of fillers, reinforcements, additives (for

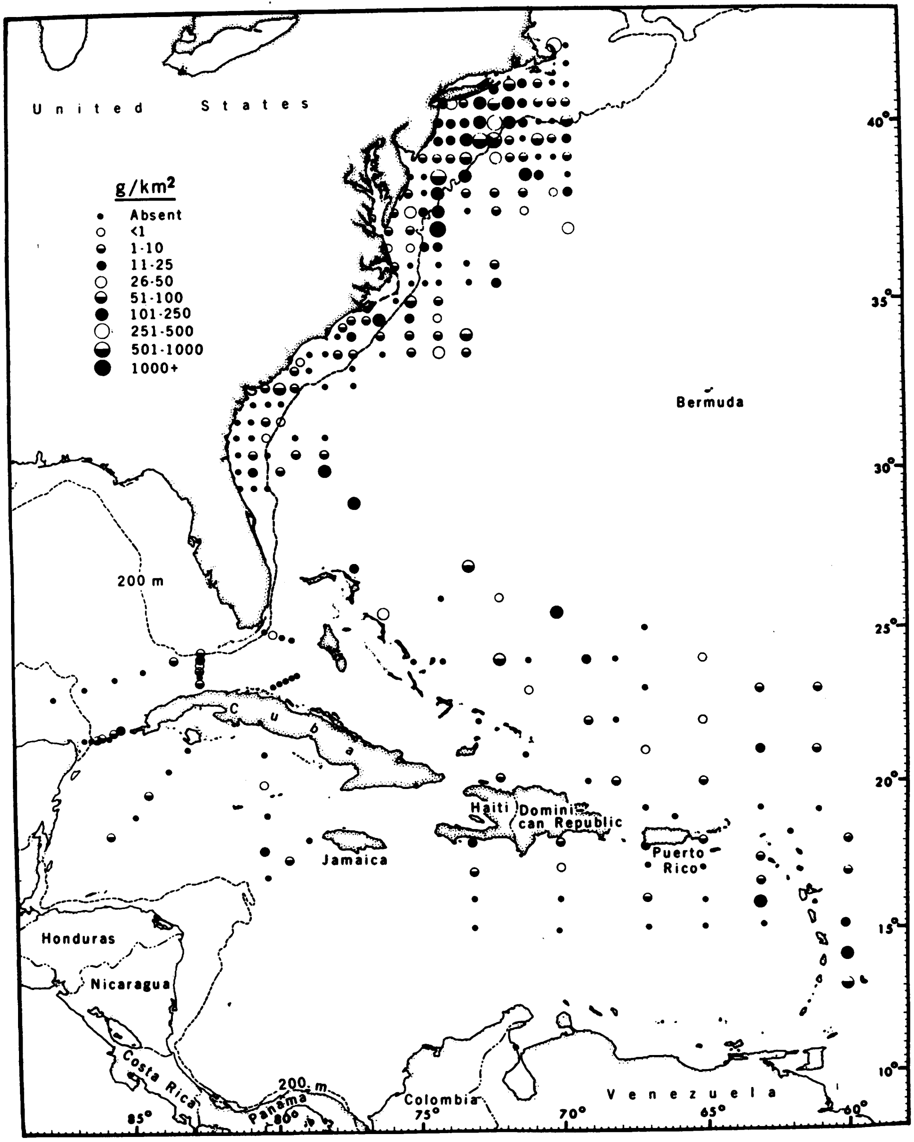

Fig. 6. Distribution of plastic sheets and pieces.

example, plasticizers, colorants, and stabilizers), and other basic materials (*25*). The estimated U.S. resin production in 1975 is 34 × 10^9 pounds and at least 55 × 10^9 pounds in 1980 (*25*).

Even without the anticipated increased production of plastics, we can expect an increase in the abundance of polystyrene spherules and polyethylene cylinders in the open ocean because of the appreciable period between the time these particles are introduced into rivers and estuaries and the time they reach the open ocean. Furthermore, we can predict an increase in the abundance of all types of plastic particles in the Sargasso Sea, which is an ocean region more favorable to the accumulation and retention of floating material than to its dispersal.

Preventive Measures

The bulk of the plastic material collected consisted of one-time-use wrapping and packaging wastes. It is our experience that a high percentage of the Styrofoam found in the ocean comes from disposable cups. The disposal of these materials at sea may be stopped if all vessels are required to install nonatmospheric polluting incinerator systems or equipment for compacting these and other solid waste materials at sea for disposal or reclamation ashore. In addition, vessel owners should discourage the use of disposable plastic tableware and food containers.

Among the technological developments and methodology needed are:

1) Development of water-soluble and photodegradable polymers for one-time-use and short-time-use plastic products.

2) Development of efficient, nonatmospheric polluting incinerators to replace open dumping and sanitary landfill.

3) Increased effort in the technological development of plastic reclamation systems.

4) Increased efforts in plastic recycling to a level of that in the paper, metal, and glass industries. This will require not only new technological development but also a change in attitude concerning the use of scrap and reprocessed material among resin producers, designers, and buyers of molded products.

Contrary to the conclusion based on the plant emission study by the Society of the Plastics Industry, Inc. (*15*), the widespread distribution of polystyrene spherules and polyethylene disks in rivers, estuaries, and the open ocean suggests that improper waste-water disposal is common practice in the plastics industry. Strong federal, state, and municipal pollution control and monitoring programs are necessary to prevent the emission of plastic beads into the waste-water systems of plastic-producing and plastic-processing plants.

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Social Origins of American Scientists and Scholars

Scholarly doctorates come disproportionately from religious groups having certain beliefs and values.

Kenneth R. Hardy

Are scientists and other scholars recruited equally from all parts of the population in the United States, or do they come disproportionately from selected segments of the citizenry? In previous work this question has been examined from religious, geographical, academic, social class, and familial aspects. A number of these studies will be briefly reviewed to provide background for the present investigation. Because there are changes over time which need to be considered, important dates will be reported.

Previous Research

In 1931, Lehman and Witty (*1*) reported a study of 1189 scientists noted as eminent in the 1927 edition of *American Men of Science* who were also listed in the 1926 to 1927 edition of *Who's Who in America*. By means of the latter publication, Lehman and Witty were able to investigate the current (adult) religious membership of the scientists. Religious affiliation of any kind was shown for the scientists only half as often (25 as opposed to 50 percent) as it was for *Who's Who*

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