Marine Pollution Bulletin, Vol. 18, No. 6B, pp. 311-316, 1987.
Printed in Great Britain.

0025-326X/87 $3.00+0.00

Patterns in the Abundance of Pelagic Plastic and Tar in the North Pacific Ocean, 1976–1985

ROBERT H. DAY and DAVID G. SHAW
Institute of Marine Science, 200 O'Neill Building, University of Alaska, Fairbanks, AK 99775-1080, USA

We determined the distribution and abundance of pelagic plastic and tar in the subtropical and subarctic North Pacific and the Bering Sea in June–August 1985 and compared them with similar observations from the same areas in 1976 and 1984. Large (aproximately 2.5 cm diameter or larger) plastic objects were counted from the deck of a ship, and small plastic objects and tarballs were caught with a neuston net. Densities (number items m^{-2}) of large plastic in subtropical waters averaged two times those in subarctic waters and eight times those in the Bering Sea. Concentrations (mg m^{-2}) of small plastic in subtropical waters averaged 26 times those in subarctic waters and 400 times those in the Bering Sea. Concentrations of tar in subtropical waters averaged three times those in subarctic waters; no tar was found in the Bering Sea. Densities of large plastic along 155°W in the Subarctic North Pacific were not significantly different between 1984 and 1985. Concentrations of small plastic increased significantly between 1976 (along 158°W) and 1985 (along 155°W), probably because of escapement into and subsequent accumulation in the oceans. Concentrations of tar decreased, although not significantly, between 1976 and 1985, possibly because of decreased dumping of petroleum compounds at sea. Densities of large plastic were strongly correlated with both densities and concentrations of small plastic, but neither densities nor concentrations of large or small plastic were correlated with densities or concentrations of tar.

The occurrence of pelagic plastic and tar has been studied less in the North Pacific and Bering Sea than in the North Atlantic, Mediterranean Sea, and Caribbean Sea (Carpenter & Smith, 1972; Colton *et al.*, 1974; Morris, 1980a,b; National Academy of Sciences, 1985). Venrick *et al.* (1973) and Dahlberg & Day (1985) reported on the quantitative distribution of large floating plastic and other debris visible from ships in the North Pacific. The distribution and abundance of pelagic tar and small plastic collected in neuston nets from the North Pacific and Bering Sea were reported by Wong *et al.* (1974, 1976), Shaw (1977), and Shaw & Mapes (1979). These studies found that pelagic plastic and tar are most abundant in the central subtropical and western North Pacific, suggesting an association with tanker and general ship traffic in the western Pacific and the 'downstream effects' of pollutants entering the ocean near Japan and adjacent countries. Abundances of both pollutants are higher in subtropical waters than in subarctic waters; the lack of significant correlation between the abundances of plastic and tar, however, indicates that there are differences in either the sources or the persistence of these materials.

We conducted this study to determine the patterns of distribution of pelagic pollutants in the North Pacific Ocean and Bering Sea and to resample in 1985 a transect that had been sampled for large plastic in 1984 and for small plastic and tar in 1976. This resampling provided information about the temporal changes in the oceanic density of plastics, and offered insight on the effects of changes in the loading, ballasting, and transportation of crude oil along the west coast of North America that occurred when Alaska's Prudhoe Bay field began production in 1977.

Methods

Data collection—large plastic

Data on the at-sea density of large (approximately 2.5 cm diameter or larger), visible pieces of plastic were collected with a strip-transect sampling method (Dahlberg & Day, 1985). Essentially, the numbers of pieces of large plastic (and other marine debris) seen within 50 m of one side of the ship were counted by an observer using 10× binoculars. Dahlberg & Day (1985) evaluated the limitations of this technique and concluded that a sampling strip 50 m wide is appropriate. Hourly information on the ship's speed allowed calculation of the area sampled and, therefore, the density of plastic objects in a particular area. We conducted a series of 49 daily transects for large plastic (Fig. 1), sampling a total of 313 km^2 of surface waters; each day's transect observations constituted one station. We did not sample when the sea conditions were so rough that we felt that we were not able to see all piece of debris.

Sample collection and analysis—neuston samples

Samples of small plastic and tar were collected with a ring net (mouth diameter 1.3 m; length 4.5 m; mesh sizes 3.0 mm in the upper 3 m and 0.333 mm in the lower 1.5 m) towed horizontally as a neuston sampler. Sampling was conducted for 10 min. each day at a ship's speed of 4.6–7.8 km h^{-1}, with most samples collected at 5.6 km h^{-1}. During sampling, we recorded coordinates, ship's speed, and width of net opening at water's surface (±0.1 m). We collected 32 neuston samples (Fig 1) with an average sampling area of 950 m^2 of ocean surface (total area sampled ≈ 0.031 km^2).

The samples were washed into a bucket and sorted in a shallow pan. Pieces of plastic and tar were removed and placed in separate, preweighed (model H51 Mettler balance) vials, then stored at 5°C. The smallest pieces of plastic and tar sorted were about 0.5 mm in diameter. In the laboratory, the sample vials were dried at room temperature, then weighed on the same balance to determine the net weights of plastic and tar samples (± 1 mg) at each station. Areas of ocean surface sampled at each station were used to calculate densities and concentrations of plastic and tar.

Data analysis

In this paper, the term density refers to the number of items per unit area and the term concentration refers to the mass of a kind of pollutant per unit area. All 1985 estimates are of mean values ±95% confidence intervals. Means were calculated for Subtropical North Pacific waters (south of 39°N, following Dahlberg & Day, 1985), Subarctic North Pacific waters (39°N or northward), and Bering Sea waters.

We tested for differences in statistical distributions of densities of large plastic in the Subarctic North Pacific between 1984 (data from Dahlberg & Day, 1985) and 1985 with a Smirnov test (Conover, 1980); the data were collected along 155°W in both years. We also tested for differences in statistical distributions of concentrations of small plastic and tar in the Subarctic North Pacific between 1976 (data from Shaw & Mapes, 1979) and 1985 with a Smirnov test. Although the 1976 data were collected along 158°W and the 1985 data were collected along 155°W, the two sampling areas were close enough to permit comparisons.

We calculated Pearson product-moment correlations among densities and concentrations of large plastic, small plastic, and tar with a BMDP P6D correlation programme (Dixon *et al.*, 1983). The correlation coefficients then were tested for significance, using tables presented in Zar (1984).

Results

General patterns

In 1985, there was great variation among different areas in densities and concentrations of plastic and tar (Table 1). The mean density of large plastic objects in subtropical waters was about twice that in subarctic waters and about eight times that in Bering Sea waters. The mean density of small plastics in subtropical waters was about 28 times that in subarctic waters and about 960 times that in the Bering Sea. The mean concentration of small plastics in subtropical waters was about 26 times that in subarctic waters and about 400 times that in the Bering Sea. The mean density of tar was the same in subtropical waters as in subarctic waters, whereas the mean concentration was about three times as much; no tar was found in the Bering Sea.

Within the North Pacific, different water-masses had different concentrations of plastic and tar in 1985. Figs 2–4 show densities of large plastic objects and concentrations of small plastic and tar on a north–south line along 155°W in the central North Pacific. Approximate boundaries of water masses were determined from hydrographic data (Hokkaido University, 1986); terminology for domains follows that of Favorite *et al.* (1976).

Densities of large plastic were high in the Alaskan Stream in 1985 (Fig. 2), decreasing with increased

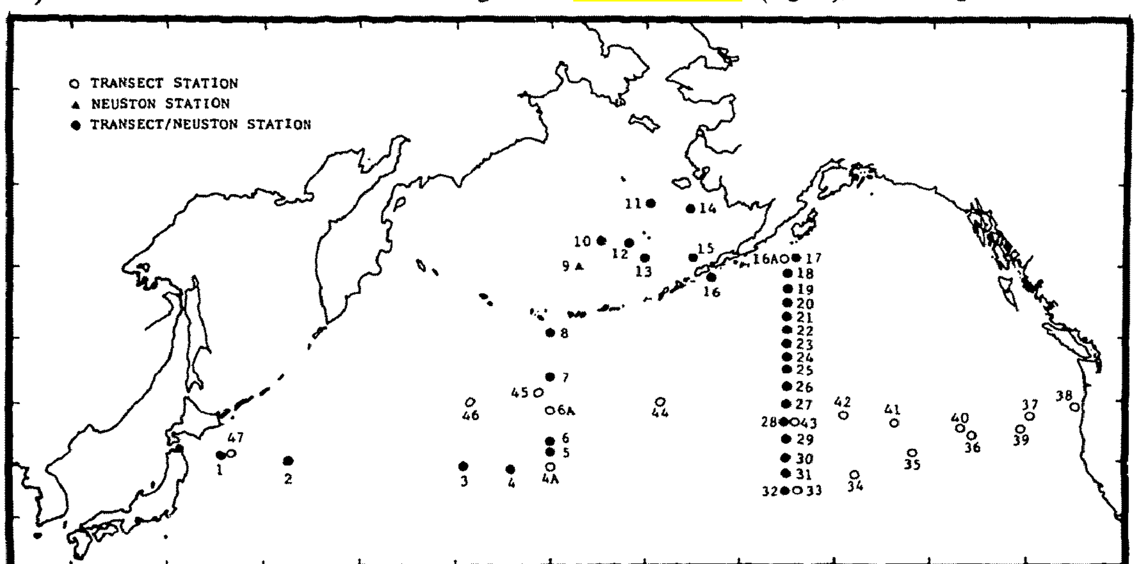

Fig. 1 Locations of stations sampled for large plastic (transect stations) and for small plastic and tar (neuston stations) in 1985.

TABLE 1

Abundance of large plastic, small plastic and tar in the North Pacific and Bering Sea, 1972–1985. For the present study, mean densities and mean concentrations ±95% confidence intervals are calculated for each major oceanographic regime sampled.

Debris type and location	Year	Area sampled (km^2)	Sample size (n)	Mean density (objects · km^{-2})	Mean concentration (mg · m^{-2})	Reference
LARGE PLASTIC						
Subtropical North Pacific	1972	13	–	2.24	–	Venrick *et al.*, 1973
Subtropical North Pacific	1984	133	26	3.15	–	Dahlberg & Day, 1985
Subtropical North Pacific	1985	33	4	1.83 ± 2.41	–	This study
Subarctic North Pacific	1984	91	17	0.15	–	Dahlberg & Day, 1985
Subarctic North Pacific	1985	245	39	0.94 ± 1.22	–	This study
Bering Sea	1985	35	6	0.23 ± 0.19	–	This study
SMALL PLASTIC						
Subtropical North Pacific	1972	0.059	33	–	0.3	Wong *et al.*, 1974
Subtropical North Pacific	1976	0.010	14	–	0.1	Shaw & Mapes, 1979
Subtropical North Pacific	1985	0.0012	2	96100 ± 780000	1.21 ± 11.31	This study
Subarctic North Pacific	1976	0.010	14	0	0	Shaw & Mapes, 1979
Subarctic North Pacific	1985	0.021	22	3370 ± 2380	0.0458 ± 0.0547	This study
Eastern North Pacific	1972	0.0072	4	0	0	Wong *et al.*, 1974
Gulf of Alaska	1974–75	0.038	51	132	–	Shaw, 1977
Bering Sea	1974–75	0.0015	20	68	–	Shaw, 1977
Bering Sea	1985	0.0085	8	80 ± 190	0.0030 ± 0.0071	This study
TAR						
Subtropical North Pacific	1972	0.059	33	–	3.8	Wong *et al.*, 1974
Subtropical North Pacific	1976	0.010	14	–	0.22	Shaw & Mapes, 1979
Subtropical North Pacific	1985	0.0012	2	1710 ± 2720	0.0215 ± 0.2440	This study
Subarctic North Pacific	1976	0.010	14	–	0.0252	Shaw & Mapes, 1979
Subarctic North Pacific	1985	0.019	21	1750 ± 1160	0.00722 ± 0.00488	This study
Eastern North Pacific	1972	0.0072	4	0	0	Wong *et al.*, 1974
Gulf of Alaska	1974–75	0.038	51	–	3.35	Shaw, 1977
Bering Sea	1974–75	0.0015	20	–	0.335	Shaw, 1977
Bering Sea	1985	0.0085	8	0 ± 0	0 ± 0	This study

distance from land. Elsewhere in the Alaskan Stream (e.g., Stations 8, 16, and 16A; see Fig. 1), large plastic was recorded at all stations also. No large plastic was found in the centre of the Alaskan Gyre in 1985 (Fig. 2); elsewhere in the Alaskan Gyre (e.g., Stations 7, 45, and 46; see Fig. 1), either no plastic or densities less than 0.5 objects · km^{-2} were recorded. Densities were slightly higher in the Subarctic Current and higher yet in the Transitional Domain (Fig. 2) throughout the Pacific (e.g., Stations 3–6, 35–37, and 39–40; see Fig. 1). The highest densities of all were found in the northern North Pacific Central Water, immediately south of the Subarctic Front (Fig. 2), and at Station 47, just east of Japan (23.7 objects · km^{-2}).

A similar pattern of abundance was found for small plastic along 155°W in 1985 (Fig. 3). Concentrations were relatively high in the Alaskan Stream and very low in the Alaskan Gyre; they then increased in the Subarctic Current and the Transitional Domain and reached a high value just south of the Subarctic Front. A similar pattern was seen in the concentration of tar north of 39°N along 155°W in 1985 (Fig. 4), but there was no major increase in concentration just south of the Subarctic Front, as was found for both large and small plastics.

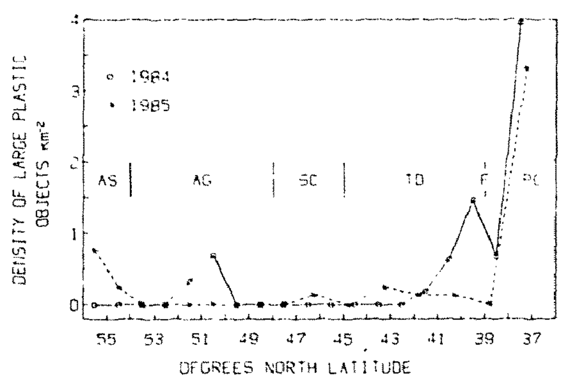

Fig. 2 Comparison of densities of large plastic along 155°W in 1984 (data from Dahlberg & Day, 1985) and 1985 (Stations 17–32 from North to South; see Fig. 1). The approximate locations of domains and their abbreviations (following Favorite *et al.*, 1976) are: AS=Alaskan Stream; AG=Alaskan Gyre (Ridge Domain); SC=Subarctic Current; TD=Transitional Domain; F=Subarctic Front; and PC=North Pacific Central Water.

Temporal changes

Table 1 indicates marked changes among years in amounts of plastic and tar in the major geographic regions of the North Pacific. These changes cannot be attributed directly to temporal effects, however, since there also are substantial year-to-year differences in sampling coverage within each major region. As illustrated in Figs 2–4, differences in relative sampling effort between water-masses within a region can lead to substantial changes in the observed mean for the region. In an effort to examine temporal effects without the confounding problem of changes in sampling coverage, we compared statistical distributions of abundances along a north–south transect that had been sampled in three different years.

The densities of large plastic along 155°W in the Subarctic North Pacific were not significantly different between years (Fig. 2; Smirnov test; $T=0.1161$; $m=14$, $n=16$; $p>0.05$), indicating that there were no major changes in plastic density in this region over a one-year period. There was significantly less small plastic in the

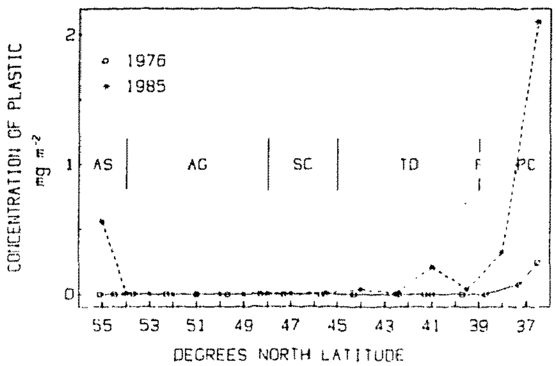

Fig. 3 Comparison of concentrations of small plastic between 1976 (along 158°W; data from Shaw & Mapes, 1979) and 1985 (along 155°W). Abbreviations for domains follow those in Fig. 2.

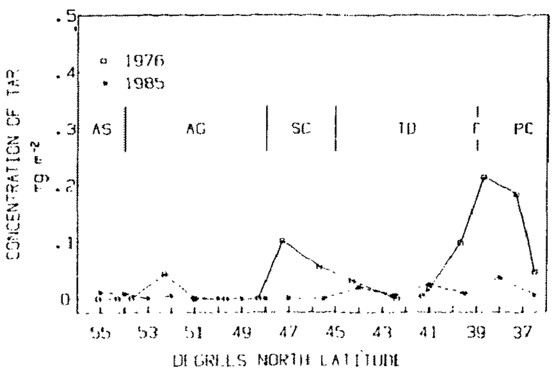

Fig. 4 Comparison of concentrations of tar between 1976 (along 158°W; data from Shaw & Mapes, 1979) and 1985 (along 155°W). Abbreviations for domains follow those in Fig. 2.

Subarctic North Pacific in 1976 (along 158°W) than in 1985 (along 155°W; Fig. 3; Smirnov test; $T=0.6429$; $m=14$, $n=14$; $p<0.05$). Tar concentrations in the Subarctic North Pacific, however, were not significantly different between 1976 and 1985 (Fig. 4; Smirnov test; $T=0.3571$; $m=14$, $n=14$; $p>0.05$).

Correlations among abundances of pollutants

Both the density of small plastic and the concentration of small plastic were strongly correlated with the density of large plastic in the North Pacific and Bering Sea (Table 2), suggesting similarity in origin or in concentrating or dispersing mechanisms. There were low correlations ($r<0.17$) between the density or concentration of small plastics and the density or concentration of tar (Table 2), suggesting geographic differences in inputs or differences in weathering rates between tar and plastics.

Discussion

General patterns

The general patterns of distribution and abundance of all three types of pollutants found here agree with previous studies. The greatest abundances occur in the western and central subtropical Pacific, consistent with previous observations that shipping around Japan is the primary source (Wong *et al.*, 1974, 1976; Takatani *et al.*, 1986). After entering the ocean, pelagic plastic and tar move in the North Pacific in response to winds and currents. For example, the importance of winds and currents (Roden, 1970) is indicated by the greater abundance of plastic and tar in subtropical water than in subarctic water and by the fact that the Alaskan Gyre, a divergent circulation feature (Favorite *et al.*, 1976), contains little or no plastic, apparently because any flotsam that enters this area is entrained in the outward surface flow.

TABLE 2

Results of correlation analyses of abundance data for plastic and tar at all stations in the North Pacific and Bering Sea, 1985. Concentration and density are defined in the text (see Methods). Sample-sizes are 31 for all correlations.

Variable 1	Variable 2	r	p
Density small plastic	Density large plastic	0.823	<0.001
Concentration small plastic	Density large plastic	0.821	<0.001
Density small plastic	Density tar	0.120	0.508
Concentration small plastic	Density tar	0.102	0.574
Density small plastic	Concentration tar	0.161	0.373
Concentration small plastic	Concentration tar	0.126	0.488

We are unsure why there was so little plastic (both large and small) and tar in the Bering Sea, since the beaches there are heavily littered with plastic trash (Merrell, 1980). The absence of large population centres bordering the Bering Sea, as well as recent reductions in foreign fishing (and subsequent reductions in plastic trash washed up on beaches; Merrell, 1984), probably play a major role in maintaining these low densities, however. The lack of tar in the Bering Sea may simply reflect the lack of tanker traffic in that area (Wong *et al.*, 1976) or may involve more complex or poorly-understood relationships, such as the effects of sea-ice formation on the persistence of tarballs.

Floating fragments of trawl-nets and monofilament gill-nets, which appear to become concentrated in the southern Transitional Domain and the North Pacific Central Water, pose a hazard to fishes, sea turtles, seabirds, and marine mammals (DeGange & Newby, 1980; Shomura & Yoshida, 1985). Dahlberg & Day (1985) found one piece of trawl-net and three pieces of gill-net in the zone 36–39°N in 1984. In 1985, we saw five fragments of trawl-net (the largest was approximately 3×4 m) and six fragments of gill-net (the largest was approximately 5–10×8 m). All but one net (at 44°N 149°W) were in the zone 37–42°N, and at least one gill-net was still 'ghost-fishing' (as judged by the presence of an entangled live fish). At least three of these net fragments were bleached and heavily encrusted, suggesting long residence at sea.

In some surveys of marine plastic, spherules or pellets of unfabricated ('raw') plastic are the principal items observed (Carpenter & Smith, 1972; Colton *et al.*, 1974; Gregory, 1978, 1983; Morris, 1980b). Only 7 of 187 pieces (3.7%) of small plastic found in this study were 'raw' unfabricated pellets, all of which were white and were 2–5 mm in diameter; all seven raw pellets were found south of 41°30′N. Although the sample size is small, the data suggest a near-absence of raw plastic pellets in the Subarctic Pacific, especially in the northern part near the coast of Alaska.

Temporal changes

Analyses of temporal differences in large and small plastic and tar provide information about the time-scales on which these abundances are changing. The lack of significant differences in densities of large plastic between 1984 and 1985 illustrates that changes in abundance over broad geographic areas occur more slowly than one year. This result seems reasonable, since plastics especially are long-lived pollutants that probably require extended times to be distributed broadly over this large geographic area. Over a sampling interval of 9 years (1976–1985) we found significant differences in concentrations of small plastic but not of tar (although there was, in general, less tar in 1985 than in 1976). If these changes continue uniformly, intervals of 5–10 years may be adequate for assessing temporal changes in the abundance of pelagic plastic and tar in the North Pacific.

The factors responsible for the increase in small plastic in the Subarctic Pacific between 1976 and 1985 are unclear, since neither the rate of input nor the lifetime of the plastic are known. The rate of increase of plastic production world-wide has slowed in recent years (Anon, 1985), and production of plastic litter is believed to be directly proportional to total production of plastics (Guillet, 1974). Estimates of plastic lifetimes are highly imprecise; Gregory (1978, 1983) estimated that it would take 3–50 years for complete degradation of plastic on beaches and much longer at sea. It is possible that the increased abundance of plastic in the Subarctic North Pacific reflects a continuing increase in the rate of input during the last 9 years. Because of a long lifetime at sea, however, the abundance of plastic would probably continue to increase even after the rate of input began to decline.

Although the mean concentration of tar in the Subarctic North Pacific in 1985 was not significantly less than that in 1976, it did average about one-third of that in 1976, and the 1985 mean from only two subtropical samples was about one-tenth that of the 1976 samples. This decrease could be the result of a series of increasingly-stringent maritime laws over the last 30 years that were designed to decrease oil pollution from ships. Although not yet fully implemented, these laws have reduced discharges of oily waste from both general shipping and crude oil carriers (National Academy of Sciences, 1985). It appears that these decreases in overall inputs have more than offset any added inputs associated with the increase in crude oil transport along the west coast of North America from 1977 onward, when oil fields in arctic Alaska went into production.

Correlations among abundances

We found no significant correlations between den sities or concentrations of either large or small plastic and the concentration of tar. Although, in a very general sense, plastic and tar are found together (compare Figs 2–4), the amount of variation is extremely high. This finding agrees with that of Shaw & Mapes (1979) but is based on a geographically-broader data set. The fact that the poor correlations occur over a broad geographic area suggests that differences between the lifetimes of plastic and tar play a bigger role in causing the poor correlations than do geographic differences in inputs of these pollutants. Another factor possibly related to the difference in lifetimes is the high correlation between abundances of large and small plastics. This high correlation and the fact that 96.3% of the small plastic ($n = 187$) consisted of fragments of larger objects suggest to us that much of the small plastic was generated at sea from large plastic. Thus, the low correlations between abundances of tar and small plastic probably result in part from differences between factors affecting the distribution of tar and those affecting the distribution of large (rather than small) plastic. Likewise, small tarballs are known to be formed from larger tarballs (Butler, 1975); however, large tarballs probably have much shorter lifetimes than do large plastic objects. Large tarballs have not been observed in the North Pacific and probably do not constitute an *in situ* source for tar.

The 1985 data were collected while Day was an Angus Gavin Memorial Fellow at the University of Alaska. We thank Capt. K. Masuda and the officers and crew of the T/V *Oshoro Maru* for help in collecting the neuston samples; special thanks go to R. Uemoto, T. Yosoe, Y. Matsui, and M. Kawakita. J. L. Sease provided statistical advice; J. L. Sease and H. K. Stockholm provided help in drafting Fig. 1. This paper has benefited from criticial comments of D. D. Gibson, S. W. Johnson, B. F. Morris, S. F. Sugai, D. A. Wolfe, and an anonymous reviewer. This is publication number 622 of the Institute of Marine Science, University of Alaska, Fairbanks, Alaska.

Anonymous (1985). Plastics: growth is continuing, but slower. *Chem. Eng. News* **63**(34), 4

Butler, J. N. (1975). Evaporative weathering of petroleum residues: the age of pelagic tar. *Mar. Chem.* **3**, 9–21.

Carpenter, E. J. & Smith, K. L., Jr. (1972). Plastics on the Sargasso Sea surface. *Science* **175**, 1240–1241.

Colton, J. B., Jr., Knapp, F. D. & Burns, B. R. (1974). Plastic particles in surface waters of the northwestern Atlantic. *Science* **185**, 491–497.

Conover, W. J. (1980). *Practical Nonparametric Statistics*, 2nd ed. Wiley, New York, NY.

Dahlberg, M. L. & Day, R. H. (1985). Observations of man-made objects on the surface of the North Pacific Ocean. In *Proceedings of the Workshop on the Fate and Impact of Marine Debris* (Shomura, R. S. & Yoshida, H. O., eds), pp. 198–212. U.S. Dep. Commer., NOAA Techn. Memo. NMFS, NOAA-TM-NMFS-SWFC-54.

DeGange, A. R. & Newby, T. C. (1980). Mortality of seabirds and fish in a lost salmon driftnet. *Mar. Pollut. Bull.* **11**, 322–323.

Dixon, W. J., Brown, M. B., Engleman, L., Franc, J. W., Hill, M. A., Jennrich, R. I. & Toporek, J. D. (1983). *BMDP Statistical Software Manual*. University of California Press, Berkeley, CA.

Favorite, F., Dodimead, A. J. & Nasu, K. (1976). Oceanography of the Subarctic Pacific region, 1960–71. *Intern. N. Pac. Fish. Comm., Bull* 33, 1–187.

Gregory, M. R. (1978). Accumulation and distribution of virgin plastic granules on New Zealand beaches. *N. Z. J. Mar. Freshwat. Res.* **12**, 399–414.

Gregory, M. R. (1983). Virgin plastic granules on some beaches of eastern Canada and Bermuda. *Mar. Environ. Res.* **10**, 73–92.

Guillet, J. E. (1974). Plastics, energy, and ecology—a harmonious triad. *Plast. Eng.* **30**, 48–56.

Hokkaido University. (1986). Data record of oceanographic observations and exploratory fishing, No. 29. Faculty of Fisheries, Hokkaido University, Hakodate, Japan, pp. 1–348.

Merrell, T. R., Jr. (1980). Accumulation of plastic litter on beaches of Amchitka Island, Alaska. *Mar. Environ. Res.* **3**, 171–184.

Merrell, T. R., Jr. (1984). A decade of change in nets and plastic litter from fisheries off Alaska. *Mar. Pollut. Bull.* **15**, 378–384.

Morris, R. J. (1980a). Floating plastic debris in the Mediterranean. *Mar. Pollut. Bull.* **11**, 125.

Morris, R. J. (1980b). Plastic debris in the surface waters of the South Atlantic. *Mar. Pollut. Bull.* 11, 164–166.
National Academy of Sciences. (1985). *Oil in the Sea: Inputs, Fates, and Effects.* National Academy Press, Washington, DC.
Roden, G. I. (1970). Aspects of the mid-Pacific transition zone. *J. Geophys. Res.* 75, 1097–1109.
Shaw, D. G. (1977). Pelagic tar and plastic in the Gulf of Alaska and Bering Sea: 1975. *Sci. Tot. Environ.* 8, 13–20.
Shaw, D. G. & Mapes, G. A. (1979). Surface circulation and the distribution of pelagic tar and plastic. *Mar. Pollut. Bull.* 10, 160–162.
Shomura, R. S. & Yoshida, H. O. (eds). (1985). *Proceedings of the Workshop on the Fate and Impact of Marine Debris.* U.S. Dep. Commer., NOAA Techn. Memo. NMFS, NOAA-TM-NMFS-SWFC-54.
Takatani, S., Sagi, T. & Imai, M. (1986). Distributions of floating tars and petroleum hydrocarbons at the surface in the western North Pacific. *Oceanogr. Mag.* 36, 33–42.
Venrick, E. L., Backman, T. W., Bartram, W. C., Platt, C. J., Thornhill, M. S. & Yates, R. E. (1973). Man-made objects on the surface of the central North Pacific Ocean. *Nature (London)* 241, 271.
Wong, C. S., Green, D. R. & Cretney, W. J. (1974). Quantitative tar and plastic waste distributions in the Pacific Ocean. *Nature (London)* 247, 30–32.
Wong, C. S., Green, D. R. & Cretney, W. J. (1976). Distribution and source of tar on the Pacific Ocean. *Mar. Pollut. Bull.* 7, 102–106.
Zar, J. H. (1984). *Biostatistical Analysis*, 2nd ed. Prentice-Hall, Englewood Cliffs, NJ.

Marine Pollution Bulletin, Vol. 18, No. 6B, pp. 316–319, 1987.
Printed in Great Britain.
0025-326X/87 $3.00+0.00

Litter Pollution from Ships in the German Bight

GOTTFRIED J. M. VAUK and ECKART SCHREY
Inselstation Helgoland des Instituts für Vogelforschung, Vogelwarte Helgoland, Postfach 1220, D-2192 Helgoland, Federal Republic of Germany

A 60 m length of beach at Helgoland was sampled approximately every third day for a year to determine the composition of litter deposited there. A total of 8473 items with a total weight of 1320 kg were identified as shipping wastes in the 106 samples. Plastics of all types composed 75% of the items, whereas wood represented 65% of the total weight. Ships' waste from along the main shipping routes in the southern German Bight may be a dominant source of the litter. The objects found were originally manufactured in 26 different nations. The study provides an estimation of the dimensions of litter pollution in the area of the inner German Bight.

Observations and reports on garbage and litter discarded at sea have been increasing for some years. Man-made materials are spread worldwide, and concentrate on the shores of the industrial countries (Coleman & Wehle, 1984; Dixon & Dixon, 1983; Gregory, 1977; Horsman, 1982; Merrell, 1980; Morris, 1980; Morris & Hamilton, 1974; Nassauer, 1981; Ree, 1975). Some authors have used the term 'plastic beaches' to describe the accumulation of plastic litter.

Plastic litter impairs the use of beaches for leisure and recreational purposes and necessitates expensive cleaning of the beaches at holiday resorts. The removal of garbage may not be possible at many places, e.g. islands, which often are wild-life reserves. Litter from shipping has caused various problems and damage including losses of seabirds, seals and other marine organisms (Cornelius, 1975; Day *et al.*, 1984; Hartwig *et al.*, 1985; Klausewitz, 1984). Some changes have also been indicated in biocenosis in coastal areas and on the sea-bottom (Klausewitz, 1984).

Previous surveys of the impact of garbage on the German North Sea coast are restricted to the isle of Scharhörn and the Wurster Küste (Lower Saxony) during the period of a few weeks in summer 1980 (Nassauer, 1981).

This report presents the first data from the isle of Helgoland on the types, amount and origin of litter washed ashore.

Methods

The isle of Helgoland (54°11'N, 7°55'E) is situated in the German Bight. From 22 March 1983 to 19 March 1984, 106 collections were made on a beach length of 60 m in the southwest of Helgoland. The surveys of the littoral fringes took place every 3 days, so that nearly every sixth low-tide period was evaluated. The litter was removed after being recorded, so that each record represented only litter that had washed ashore recently. All countings represent minimum data, since extremely high tides can remove materials that were deposited before. Furthermore, it has to be considered, that of course only floating litter was washed ashore.

The area examined is not used by holidaymakers and visitors. It consists of sandy materials with solitary rocky fragments broken out of the cliffs.

Results and Discussion

Litter was recorded by number of items and weight in 8 categories (plastic, paper, metal, glass material, fishing gear, clothes, food stuff, and wood). A detailed list of plastic material and fishing gear is given in Table 1. Altogether, 8539 items with a total weight of 1360 kg were found during the year of survey. Most items (75%)