



# A Comparison of Plastic and Plankton in the North Pacific Central Gyre

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The potential for ingestion of plastic particles by open ocean filter feeders was assessed by measuring the relative abundance and mass of neustonic plastic and zooplankton in surface waters under the central atmospheric high-pressure cells of the North Pacific Ocean. Neuston samples were collected at 11 random sites, using a manta trawl lined with 333  $\mu$  mesh. The abundance and mass of neustonic plastic was the largest recorded anywhere in the Pacific Ocean at 334271 pieces  $\text{km}^2$  and 5114 g  $\text{km}^2$ , respectively. Plankton abundance was approximately five times higher than that of plastic, but the mass of plastic was approximately six times that of plankton. The most frequently sampled types of identifiable plastic were thin films, polypropylene/monofilament line and unidentified plastic, most of which were miscellaneous fragments. Cumulatively, these three types accounted for 98% of the total number of plastic pieces. © 2001 Elsevier Science Ltd. All rights reserved.

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Marine debris is more than an aesthetic problem, posing a danger to marine organisms through ingestion and entanglement (Day, 1980; Balazs, 1985; Fowler, 1987; Ryan, 1987; Robards, 1993; Bjorndal *et al.*, 1994; Laist, 1997). The number of marine mammals that die each year due to ingestion and entanglement approaches 100 000 in the North Pacific Ocean alone (Wallace, 1985). Worldwide, 82 of 144 bird species examined contained small debris in their stomachs, and in many species the incidence of ingestion exceeds 80% of the individuals (Ryan, 1990). In addition, a recent study has determined that plastic resin pellets accumulate toxic chemicals, such as PCBs, DDE, and nonylphenols, and may serve as a transport medium and source of toxins to marine organisms that ingest them (Mato *et al.*, 2001).

Many studies have focused on the ingestion of small debris by birds because their stomach contents can be regurgitated by researchers in the field without causing

harm to the animal. Less well studied are the effects of ingestible debris on fish, and no studies have been conducted on filter-feeding organisms, whose feeding mechanisms do not permit them to distinguish between debris and plankton. Moreover, no studies have compared the amount of neustonic debris to that of plankton to assess the potential effects on filter feeders.

Concerns about the effects of neustonic debris in the marine environment are greatest in oceanographic convergences and eddies, where debris fragments naturally accumulate (Shaw and Mapes, 1979; Day, 1986; Day and Shaw, 1987). The North Pacific central gyre, an area of high atmospheric pressure with a clockwise ocean current, is one such area of convergence that forces debris into a central area where winds and currents diminish. This study compares the abundance and mass of neustonic debris with the amount of zooplankton in this area.

## Materials and Methods

Eleven neuston samples were collected between August 23 and 26, 1999, from an area near the central pressure cell of the North Pacific sub tropical high (Fig. 1). Sampling sites were located along two transects: a westerly transect from 35°45.8'N, 138°30.7'W to 36°04.9'N, 142°04.6'W; and a southerly transect from 36°04.9'N, 142°04.6'W to 34°40.0'N. Location along the transect and trawl duration were selected randomly. Samples were collected using a manta trawl with a rectangular opening of 0.9 × 0.15 m<sup>2</sup>, and a 3.5 m long, 333  $\mu$  net with a 30 × 10 cm<sup>2</sup> collecting bag. The net was towed at the surface outside of the effects of port wake (from the stern of the vessel) at a nominal speed of 1 m s<sup>-1</sup>; actual speed varied between 0.5 and 1.5 m s<sup>-1</sup>, as measured with a B&G paddlewheel sensor. Each trawl was conducted for a random distance, ranging from 5 to 19 km. Sampling was conducted as the ship moved along the transect with an approximately even split of sampling between daylight and night-time hours. Estimates of plastic and plankton per square kilometer were obtained by using the width of the trawl net opening times the length of the trawl.

Samples were fixed in 5% formalin, then soaked in fresh water and transferred to 50% isopropyl alcohol.

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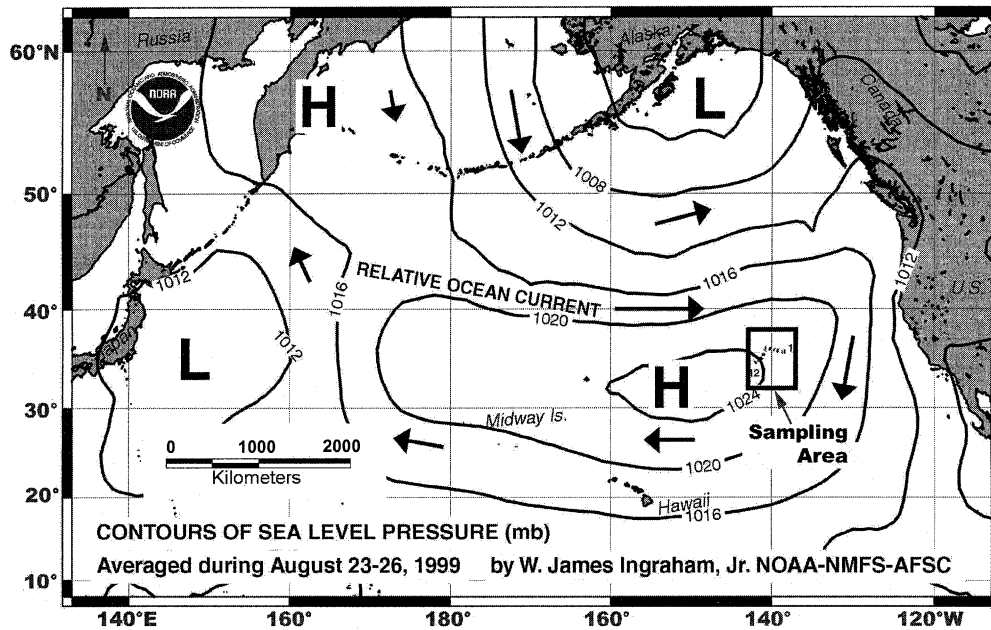


Fig. 1 Location of sampling area in the North Pacific gyre.

To separate the plastic particles from living tissue, the samples were drained and put in seawater, which floated most of the plastic to the surface, leaving the living tissue at the bottom. Top and bottom portions were inspected under a dissecting microscope. Intermixed plastic was removed from the tissue fraction and tissue was removed from the plastic fraction and placed in the appropriate containers. Plankton were counted and identified to class.

Plastic was sorted by rinsing through Tyler sieves of 4.76, 2.80, 1.00, 0.71, 0.50, and 0.35 mm. Plastic and plankton were oven dried at 65°C for 24 h and weighed. Individual pieces of plastic were categorized into standardized categories by type (fragment, Styrofoam fragment, pellet, polypropylene/monofilament line fragment, thin plastic films), and one nonplastic category (tar); then they were counted.

## Results

A total of 27 698 small pieces of plastic weighing 424 g were collected from the surface water at stations in the

gyre, yielding a mean abundance of 334271 pieces km<sup>2</sup> and a mean mass of 5114 g/km<sup>2</sup>. Abundance ranged from 31982 pieces km<sup>2</sup> to 969777 pieces/km<sup>2</sup>, and mass ranged from 64 to 30169 g km<sup>2</sup>.

A total of 152244 planktonic organisms weighing approximately 70 g were collected from the surface water, with a mean abundance of 1837342 organisms km<sup>2</sup> and mean mass of 841 g/km<sup>2</sup> (dry weight). Abundances ranged from 54003 organisms km<sup>2</sup> to 5076403 organisms km<sup>2</sup>, and weights ranged from 74 to 1618 g/km<sup>2</sup>.

Plastic fragments accounted for the majority of the material collected in the smaller size categories (Table 1). Thin plastic films, such as those used in sandwich bags, accounted for half of the abundance in the second largest size category, and pieces of line (polypropylene and monofilament) comprised the greatest fraction of the material collected in the largest size category.

Plankton abundance was higher than plastic abundance in 8 out of 11 samples, with the difference being higher at night (Fig. 2). In contrast, the mass of plastic was higher than the plankton mass in 6 out of 11 samples. The ratio of plastic-to-plankton mass was higher

TABLE 1  
Abundance (pieces km<sup>2</sup>) by type and size of plastic pieces and tar found in the North Pacific gyre.

Mesh-size (mm)	Fragments	Styrofoam pieces	Pellets	Polypropylene/monofilament	Thin plastic films	Miscellaneous		
						Tar	Unidentified	Total
> 4.760	1931	84	36	16811	5322	217	350	24764
4.759-2.800	4502	121	471	4839	9631	97	36	19696
2.799-1.000	61187	1593	12	9969	40622	833	72	114288
0.999-0.710	55780	591	0	2933	26273	278	48	85903
0.709-0.500	45196	567	12	1460	10572	121	0	57928
0.499-0.355	26888	338	0	845	3222	169	229	31692
Total	195484	3295	531	36857	95642	1714	736	334270

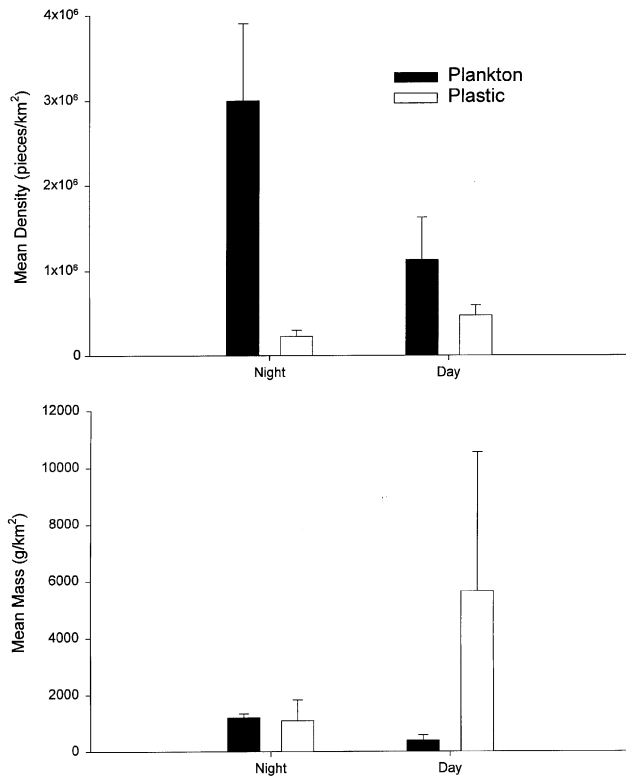


Fig. 2 Abundance and mass of plankton and plastic in night versus day samples.

during the day than at night, although much of the difference during the day was due to a plastic bottle being caught in one daylight sample and 1 m of polypropylene line being caught in the other.

## Discussion

The mean abundance and weight of plastic pieces calculated for this study are the largest observed in the North Pacific Ocean. Previous studies have estimated mean abundances of plastic pieces ranging from 3370 to 96 100 pieces km<sup>2</sup> and mean weights ranging from 46 to 1210 g km<sup>2</sup> (Day and Shaw, 1987). The highest previous single sample abundance and weight recorded for the North Pacific Ocean was taken from an area about 500 miles east of Japan. At 3 16800 pieces km<sup>2</sup> and 3492 g km<sup>2</sup> (Day *et al.*, 1990), the abundance and weight are three and seven times less than the highest sample recorded in this study, respectively.

Several possible reasons are suggested for the high abundance found in this study. The first is the location of our study area, which was near the central of the North Pacific subtropical high pressure cell. Previous studies in the North Pacific Ocean were conducted without reference to the central pressure cell (Day *et al.*, 1990), which should serve as a natural eddy system to concentrate neustonic material including plastic. However, while previous studies did not focus on the subtropical high, many studies were conducted as transects that passed through the gyre (Day *et al.*, 1986, 1988,

1990). Thus, it is unlikely that location alone was the reason for the higher densities we observed, as Day *et al.* (1990) collected samples from the western part of this same area.

An alternate hypothesis is that the amount of plastic material in the ocean is increasing over time, which Day and Shaw (1987) have previously suggested based upon a review of historical studies. Plastic degrades slowly in the ocean (Andrady, 1990; US EPA, 1992). While some of the larger pieces may accumulate enough fouling organisms to sink them, the smaller pieces are usually free of fouling organisms and remain afloat. Thus, new plastics added to the ocean may not exit the system once introduced unless they are washed ashore. Although numerous studies have shown that islands are repositories of marine debris (Lucas, 1992; Corbin and Singh, 1993; Walker *et al.*, 1997), the North Pacific Ocean has few islands except near coastal boundaries. The dominant clockwise gyral currents also serve as a retention mechanism that inhibits plastics from moving toward mainland coasts. A recent surface current modeling study simulated that most of the particles from our sampling area should be retained there for at least 12 years (Ingraham *et al.*, in press).

The large ratio of plastic to plankton found in this study has the potential to affect many types of biota. Most susceptible are the birds and filter feeders that focus their feeding activities on the photic portion of the water column. Many birds have been examined and found to contain small debris in their stomachs, a result of their mistaking plastic for food (Day *et al.*, 1985; Fry *et al.*, 1987; Ainley *et al.*, 1990; Ogi, 1990; Ryan, 1990; Laist, 1997). While no record was kept of the presence or absence of fouling organisms on plastic particles during sorting, a subsequent random sampling of each size class found 91.5% of the particles to be free of fouling organisms. As the size class decreased, there were fewer particles that showed evidence of fouling. Hence ingestion of plastic for its attached food seems unlikely, especially for organisms feeding on the surface. However, organisms such as the two filter-feeding salps (*Thetys vagina*) collected in this study which were found to have plastic fragments and polypropylene/monofilament line firmly embedded in their tissues, may have ingested the line at depth and utilized fouling organisms for food.

Although our study focused on the neuston, samples also were collected from two oblique tows to a depth of 10 m. We found that the density of plastic in these areas was less than half of that in the surface waters and was primarily limited to monofilament line that had been fouled by diatoms and microalgae, thereby reducing its buoyancy. The smaller particles that have the greatest potential to affect filter feeders were even more reduced with depth, as should be expected because of their positive buoyancy and lack of fouling organisms, noted above.

Several limitations restrict our ability to extrapolate our findings of high plastic-to-plankton ratios in the

North Pacific central gyre to other areas of the ocean. The North Pacific Ocean is an area of low biological standing stock; plankton populations are many times higher in nearshore areas of the eastern Pacific, where upwelling fuels productivity (McGowan *et al.*, 1996). Moreover, the gyre beneath the subtropic high probably serves to retain plastics, whereas plastics may wash up on shore in greater numbers in other areas. Conversely, areas closer to the shore are more likely to receive inputs from land-based runoff and ship loading and unloading activities, whereas a large fraction of the materials observed in this study appear to be remnants of offshore fishing-related activity and shipping traffic.

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