A comparison of plastic and plankton in the North Pacific central gyre

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ABSTRACT

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 near the central high-pressure area of the North Pacific central gyre. Neuston samples were collected at 11 random sites, using a manta trawl lined with 333 u mesh. The abundance and mass of neustonic plastic was the largest recorded in this area at 334,271 pieces/km^2 and 5,114 g/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 and polypropylene/monofilament line. The most frequently sampled type of unidentified plastic was plastic fragments. Cumulatively, these three types accounted for 98% of the total plastic pieces.

INTRODUCTION

Marine debris is a visible expression of human impact on the marine environment. 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).

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 pressure with a clockwise ocean current, is one such area of convergence that forces debris into a central area with little wind and current influence. This study compares the abundance and mass of neustonic debris with the amount of zooplankton in this area.

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 (Figure 1). Sampling sites were located along two transects: a westerly transect from 35º 45.8'N, 138º 30.7'W to 36º 04.9'N, 142º 04.6'W; and a southerly transect from 36º 04.9'N, 142º 04.6'W to 34º 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 m x 0.15 m, and a 3.5 m long, 333 u net with a 30 cm x 10 cm 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; actual speed varied between 0.5 and 1.5 m/s, 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

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moved along the transect with an approximately even split of sampling between daylight and night-time hours.

Samples were fixed in 5% formalin, then soaked in fresh water and transferred to 50% isopropyl alcohol. To separate plastic from living tissue, the samples were drained and put in seawater, which tended to float the plastic at the surface and leave 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 and plankton were oven dried at 65^{o} C for 24 h and weighed. Plastic was sorted by rinsing through Tyler sieves of 4.76 mm, 2.80 mm, 1.00 mm, 0.71 mm, 0.50 mm, and 0.35 mm. Individual pieces of plastic were categorized into standardized categories by type (fragment, Styrofoam fragment, pellet, polypropylene/monofilament line fragment, thin plastic films), and one non-plastic category (tar); then they were counted.

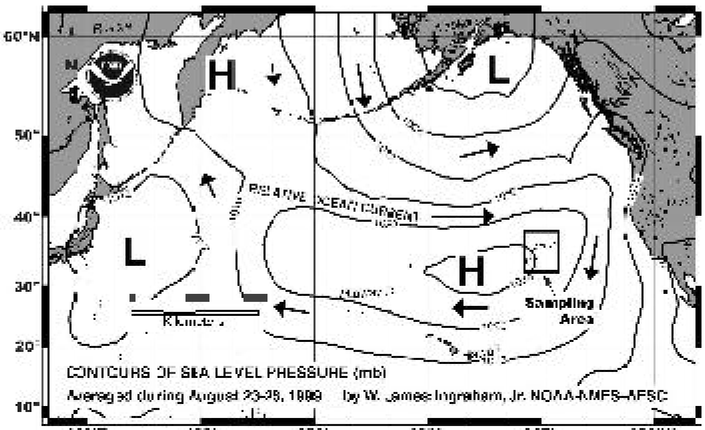


FIGURE 1. Location of sampling area in the North Pacific gyre.

RESULTS

A total of 27,698 small pieces of plastic weighing 424 g were collected from the surface water in the gyre, yielding a mean abundance of 334,271 pieces/km^2 and a mean mass of 5,114 g/km^2. Abundance ranged from 31,982 pieces/km^2 to 969,777 pieces/km^2, and mass ranged from 64 to 30,169 g/km^2.

A total of 152,244 planktonic organisms weighing approximately 70 g were collected from the surface water in the gyre, with a mean abundance of 1,837,342 organisms/km^2 and mean mass of 841 g/km^2 (dry weight). Abundances ranged from 54,003 organisms/km^2 to 5,076,403 organisms/km^2, and weights ranged from 74 to 1,618 g/km^2.

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 about 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 much higher at night (Figure 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 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 polyline 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 3,370 to 96,100 pieces/km^2 and mean weights ranging from 46 to 1,210 g/km^2 (Day and Shaw 1987). The highest previous single sample abundance and weight recorded for the North Pacific Ocean is 316,800 pieces/km^2 and 3,492 g/km^2 (Day *et al.* 1990), respectively which is three and seven times less than the highest sample recorded in this study, respectively.

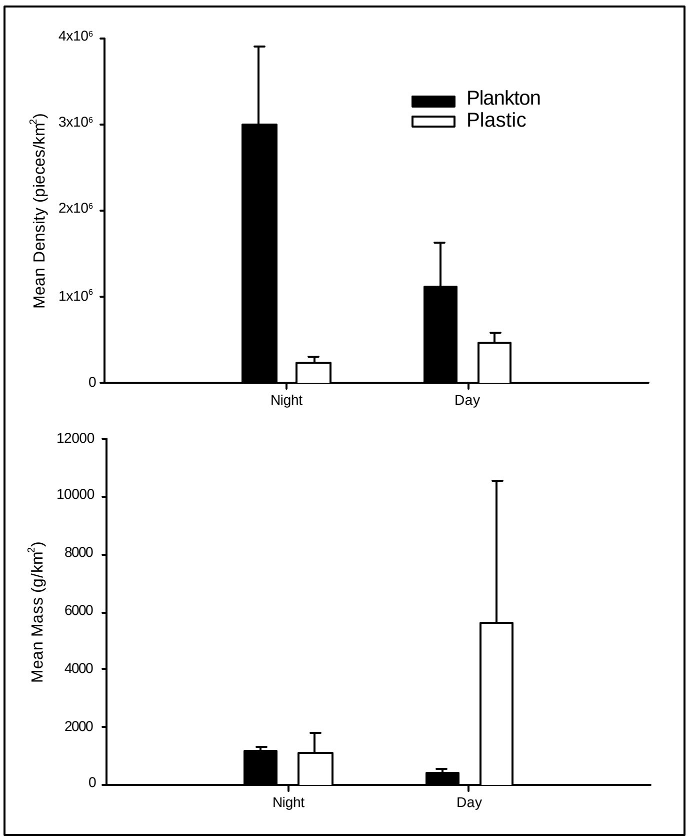
Several possible reasons were observed for the high abundance found in this study. The first is the location of our study area, which was near the central pressure cell of the North Pacific sub tropical high. Previous studies conducted in the North Pacific Ocean were conducted without reference to the 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 gyre, many studies were conducted as transects that passed through the gyre (Day *et al.* 1986, Day 1988, Day *et al.* 1990). Thus, it is unlikely that location alone was the reason for the higher densities we observed.

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, U.S. EPA 1992). While some of the larger pieces may accumulate enough fouling organisms to cause them to sink, the smaller pieces are usually free of fouling organisms and remain afloat. Thus, new plastics added to the ocean may not leave the system once introduced unless they are washed up on shore by ocean currents. Although numerous studies have shown that islands

TABLE 1. Abundance (pieces/km²) 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	Tar	Misc./ Unid.	Total
>4.760	1,931	84	36	16,811	5,322	217	350	24,764
4.759-2.800	4,502	121	471	4,839	9,631	97	36	19,696
2.799-1.000	61,187	1,593	12	9,969	40,622	833	72	114,288
0.999-0.710	55,780	591	0	2,933	26,273	278	48	85,903
0.709-0.500	45,196	567	12	1,460	10,572	121	0	57,928
0.499-0.355	26,888	338	0	845	3,222	169	229	31,692
Total	195,484	3,295	531	36,857	95,642	1,714	736	334,270

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



are repositories of marine debris (Lucas 1992, Corbin and Singh 1993, Walker *et al.* 1997), the North Pacific Ocean has few islands and the dominant eddy currents serve as a retention mechanism that prevents plastics from moving toward mainland coasts.

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 upper 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). Two filter-feeding salps (*Thetys vagina*) collected in this study were found to have plastic fragments and polypropylene/monofilament line firmly embedded in their tissues. Organisms that feed throughout the water column, such as baleen whales, are less likely to be directly affected. While 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 plastics 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.

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 eddy effects of the gyre probably serve 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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