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Note

Quantitative analysis of small-plastic debris on beaches in the Hawaiian archipelago

Karla J. McDermid *, Tracy L. McMullen

Marine Science Department, University of Hawaii at Hilo, 200 W. Kawili St., Hilo, HI 96720, USA

Abstract

Small-plastic beach debris from nine coastal locations throughout the Hawaiian Archipelago was analyzed. At each beach, replicate 20 l samples of sediment were collected, sieved for debris between 1 and 15 mm in size, sorted by type, counted and weighed. Small-plastic debris occurred on all of the beaches, but the greatest quantity was found at three of the most remote beaches on Midway Atoll and Moloka'i. Of the debris analyzed, 72% by weight was plastic. A total of 19,100 pieces of plastic were collected from the nine beaches, 11% of which was pre-production plastic pellets. This study documents for the first time the presence of small-plastic debris on Hawaiian beaches and corroborates estimates of the abundance of plastics in the marine environment in the North Pacific.

Keywords: Plastic debris; Hawaiian islands; Plastic pellets; Marine pollution; Beaches; North pacific

1. Introduction

Ninety-six percent of the plastic found in the North Pacific was small pieces of plastic (Robards et al., 1997). Such debris is composed of fragments of manufactured plastic products (user plastic), and pre-production plastic pellets (industrial pellets, virgin pellets, plastic resin beads, or nurdles) that are shipped from manufacturing plants to plastic injection factories to be melted and molded into consumer products (US EPA, 1992). Billions of these pellets, lost from container ships, down drains, and through other shipping and production mishaps, have been reported floating in coastal surface waters, in the open ocean, on beaches throughout the world, and in sediments (US EPA, 1992; Derraik, 2002). Plastic pellets and plastic fragments were collected in trawls in the North Pacific central gyre in a ratio of 6:1 plastic to plankton mass (Moore et al., 2001b). Mistaken ingestion of small pieces of plastic occurs in seabirds, fish and various planktivores (Carpenter et al., 1972; Laist, 1997). Ingestion of plastics can have harmful effects, such as diminished food consumption, loss of nutrition, internal injury, intestinal blockage, starvation, and death (Redford et al., 1997; Derraik, 2002). Plastic particles, which do not biodegrade readily, may accumulate in plankton-consuming animals, and could be passed up the food chain. In addition, plastic pellets and fragments can transfer chemical pollutants to organisms (Derraik, 2002), including polychlorinated biphenyls (PCBs), 1,1-dichloro-2,2-chlorophenylethylene (DDE) and nonylphenols (NP), which have no natural sources, and may have adverse health effects (AGTSDR, 1995a,b). Such pollutants may absorb into plastic pellets from seawater, and show a steady increase in concentration with exposure time (Mato et al., 2001).

Sampling North Pacific seabirds, which have shown a rise in plastic ingestion since the 1980s (Robards et al., 1995, 1997; Blight and Burger, 1997), is an indirect method of measuring increase in the amounts of floating plastic debris that collects in two gyres—one northwest and one northeast of the Hawaiian Islands (Ingraham, 2001; Moore et al., 2001b). Few studies have attempted to quantify the abundance and mass of neustonic debris in situ (Day et al., 1990; Ogi et al., 1990; Moore et al., 2001b), perhaps because shiptime for extensive open ocean trawls are costly and time-consuming (Fan, 1997).

* Corresponding author. Tel.: +1-808-933-3906; fax: +1-808-974-7693.
E-mail address: mcdermid@hawaii.edu (K.J. McDermid).

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The islands and atolls of the Hawaiian Archipelago stretch 1500 km from 19°N to 28°N latitude and act as a filter, garnering marine debris from passing currents (Donohue et al., 2001). Beach surveys, especially in remote locations, can be useful as an indicator of the amount of small-plastic debris in the North Pacific. Our study assessed the quantity of small-plastic debris on selected Hawaiian beaches.

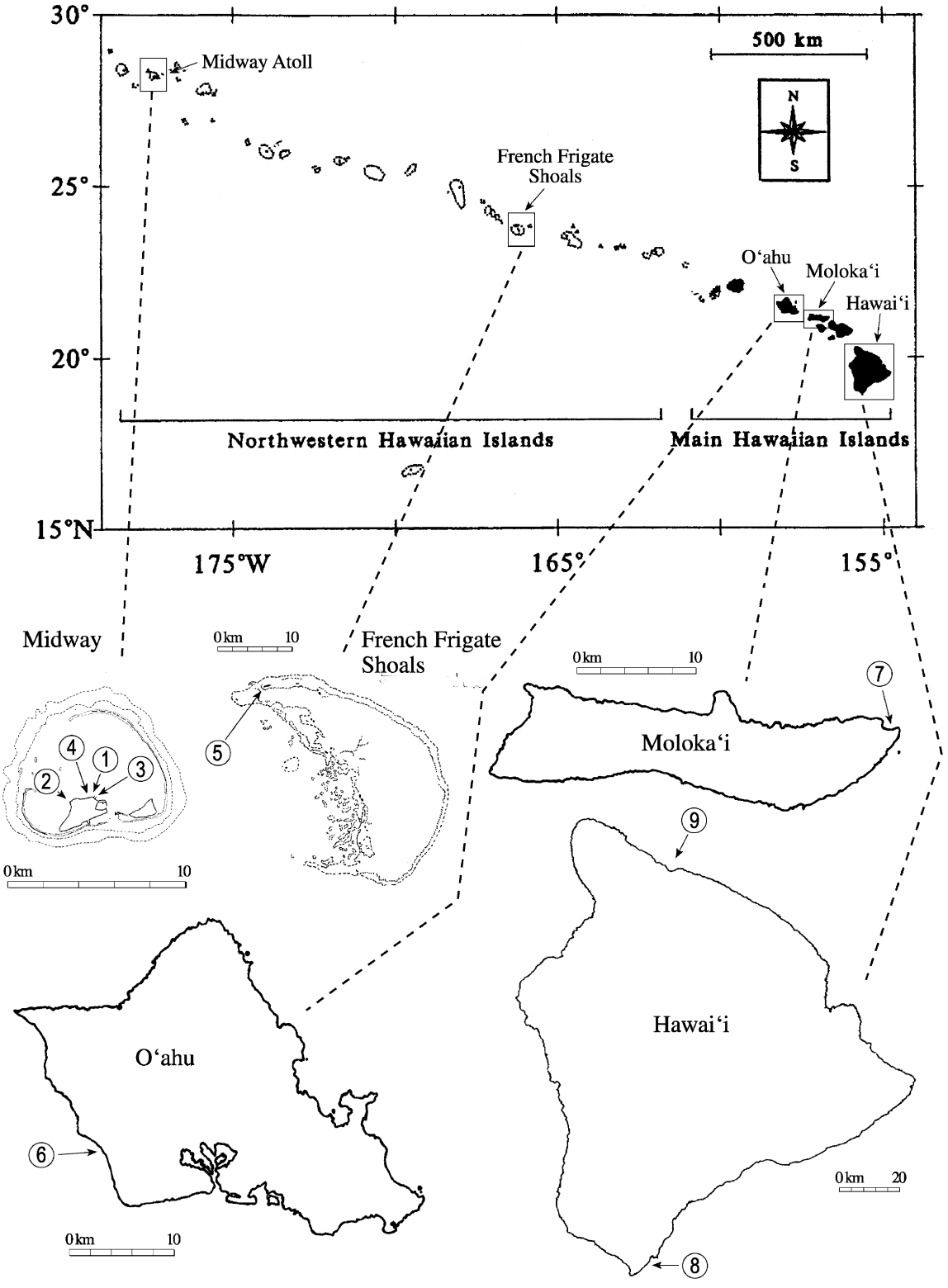

Fig. 1. Sampling locations on islands in the Hawaiian Archipelago. Numbers correspond to location numbers in Table 1.

2. Materials and methods

Nine remote locations throughout the Hawaiian Islands were sampled between September 2001 and February 2003: Cargo Beach, Rusty Bucket, North Beach and Turtle Beach on Midway Atoll, Tern Island at French Frigate Shoals, Nanakuli Beach Park on O'ahu, Halawa Valley on Moloka'i, and Waipi'o Valley and Green Sands Beach on the island of Hawai'i (Fig. 1, Table 1). None are near industrial, commercial, nor densely populated areas.

At each beach, a sediment sample was taken from the high tide line as well as from the berm or the upper part of the beach that receives wave action during storms and high surf (except Halawa sites, 2 high tide samples were collected due to lack of a berm). Each sample consisted of sand scooped with a small shovel from a 61×61 cm^2 quadrat to a depth of approximately 5.5 cm, to fill a 20 l bucket. These residues were sieved through a set of nested sieves: 4.75, 2.8, and 1 mm. Only particles 1–15 mm in size were retained from each sieve tray and placed in separate labeled plastic bags.

Sorting proceeded through the following steps (see Ogi and Fukumoto, 2000; Moore et al., 2001a).

Dry sort—Each sample was placed on a sheet of white paper. Materials were sorted into major categories: plastic, plant, and "other" (i.e. shell, paper and ceramic matter), placed in separate containers, and labeled with sieve size, location and type.

Wet sort—Each sub-sample of plastics was rinsed to remove soil and sand, and to pick out non-floatable objects that may be mistaken for plastics (glass). Small amounts of sample were poured into a container of freshwater. The container was swirled for 1 min and floating particles (mostly plastic) then sieved out. Some sub-samples required rinsing several times to remove all of the clinging sand or soil. The samples were then dried in an oven for 1 h at 65 °C.

Classification and quantification—Each size class was then separated by type of plastic (film, line, pellet, fragment, foam), counted and placed in separate containers. Each size class was weighed to 0.01 g on an Ohaus top-loading balance. Plant material and "other" non-plastic, non-plant material from each sample was sorted and weighed.

3. Results

A total of 22 samples (20 l each) were taken at nine locations. Of the 736.47 g of debris collected, 72% by weight was plastic particles, 22% was plant material, and 6% "other". Mean weight of debris per sample was 23.38 g plastic, 7.35 g plant matter, and 1.88 g "other" debris (Fig. 2). Small-plastic debris was found in every sample, totaling 19,100 pieces (Table 1). After being sorted, 87% of the plastic collected was fragments, while 11% was pre-production plastic pellets. Cargo Beach on Midway Atoll showed the greatest number of small-plastic pieces, followed by Turtle Beach, Midway and Halawa Valley North, Moloka'i. The least number of plastic pieces was collected at Nanakuli Beach Park on the leeward coast of O'ahu. Seeds of Cheeseweed (*Malva parviflora*), a non-native, herbaceous plant, were abundant in sands from both Midway Atoll and Tern Island, French Frigate Shoals, where it is a common weed (Wagner et al., 1990).

Table 1
Total amount of plastic pieces collected at each beach sorted by type

Collection sites	Date	Fragments	Pellets	Line	Film	Foam	Total
Midway Atoll							
1. Cargo Beach	23/ix/02	15,563	1890	183	6	3	17,645
2. Rusty Bucket	ix/01	9	1	0	0	0	10
3. Turtle Beach	ix/01	384	79	44	0	0	507
4. North Beach	ix/01	105	7	0	0	15	127
French Frigate Shoals							
5. Tern Island–South Beach	6/viii/02	207	57	9	2	0	275
O'ahu							
6. Nanakuli Beach Park	29/ix/02	5	0	0	1	0	6
Moloka'i							
7. Halawa Valley North	1/xii/02	243	123	0	0	8	374
7. Halawa Valley South	1/xii/02	49	7	0	1	1	58
Hawai'i							
8. Green Sands Beach	17/ii/03	57	4	20	1	0	82
9. Waipi'o Valley North	13/x/02	1	0	2	0	1	4
9. Waipi'o Valley South	13/x/02	8	1	1	0	2	12
Total		16,631	2169	259	11	30	19,100

Site numbers correspond to locations shown in Fig. 1. Two samples were taken from each beach.

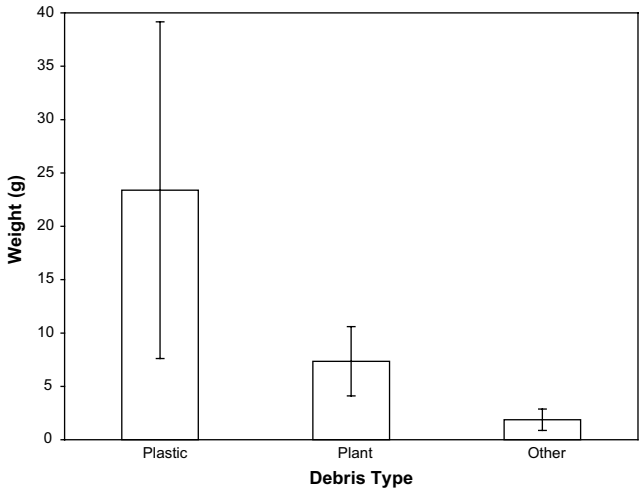

Fig. 2. Mean weight of debris per 20 l of sediment based on 22 samples at nine Hawaiian beaches. Bars represent standard error of the mean.

A greater quantity of plastic occurred at the high tide line for all sites showed than at the berm (Table 2). High tide plastic pieces totaled 18,559, and weighed 496.05 g. We collected 36.32 g of plastic (541 pieces) from berm samples. The total weight of plastic for all sites combined was 532.37 g.

In both the berm and high tide collections, the 2.8–4.75 mm size class contained the greatest quantity of plastic pieces (Table 3). Smaller pellets (1–2.8 mm) were also present, and most of these were collected at Cargo Beach, Midway Atoll. At this site, 15,563 fragments were collected, almost half of which were in the smallest size class.

Table 2
Total weight of plastic debris by type from all beach samples taken from the high tide zone ($n = 13$) and berm ($n = 9$)

	High tide (g)	Berm (g)	Total (g)
Fragments	456.20	31.13	487.33
Pellets	36.09	1.36	37.45
Line	1.81	3.63	5.44
Film	0.45	0.05	0.50
Foam	1.50	0.15	1.65
Total weight of plastic	496.05	36.32	532.37

All weights in grams.

Table 3
Abundance of plastic pieces in all beach samples combined, sorted by size range and collection site on the beaches

Size range (mm)	High tide	Berm
>4.75	1744	99
2.8–4.75	8829	280
1–2.8	7986	162

Values equal numbers of plastic pieces.

4. Discussion

Measurable amounts of small-plastic debris (1–15 mm in size) were found at all remote beaches sampled. Each beach had different current patterns, sand types, wave action, and wind exposure. It is likely that small-plastic debris affects every beach in the North Pacific, regardless of isolation or proximity to dense human population centers or shipping traffic.

Pre-production plastic pellets comprised 11% by abundance, 7% by weight, of the small-plastic debris we collected. This type of plastic pellet is known to be abundant on beaches in areas near plastic manufacturing factories, cargo loading docks, and shipping lanes for raw plastic materials (Gregory, 1978; Shiber, 1979, 1982, 1987; Nigam, 1982; Khordagui and Abu-Hilal, 1994; Fujieda, 1999; Moore et al., 2001a). We found pre-production pellets in high densities on beaches far from cities and industry, as have Gregory (1983, 1999) and Cruz et al. (1990).

Our data showed 43% of the plastic pieces collected on remote beaches were 1–2.8 mm in size. This size of particle could be ingested by planktivores, including filter-feeding salps, and surface-feeding seabirds (Bourne and Imber, 1982; Azzarello and Van Vleet, 1987; Moore et al., 2001b).

High tide line collections contained much more plastic than berm samples, perhaps because particles suspended in the water will be left on shore during every receding tide, whereas berm debris may be deposited primarily during storms, or as wind-blown debris from the high tide line. Line, film and foam particles were found in very low densities at the remote beaches: foam may be degraded in the marine environment (Andrady, 1990); and line, film and foam with large surface areas, can be fouled by marine organisms, sink out of the water column, and not be deposited on beaches.

We have shown that small-plastic debris occurs at even the most remote beaches in the North Pacific, and that pellets make up a large portion of the small-plastic debris collected. Studies are needed to correlate marine debris accumulations with currents and shipping lanes to determine sources of the debris, and to target clean up and prevention efforts. The effects of small-plastic debris on marine animals, including toxicity of pellets and fragments that wash up on beaches throughout the Hawaiian Archipelago, remains unknown, but should be investigated.

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