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Composition and Distribution of Beach Debris in Orange County, California

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Many studies have quantified debris collected on beaches around the world. Only a few of those studies have been conducted in the United States, and they are largely limited to semi-quantitative efforts performed as part of volunteer clean-up activities. This study quantifies the distribution and composition of beach debris by sampling 43 stratified random sites on the Orange County, California coast, from August to September 1998. We estimated that approximately 106 million items, weighing 12 metric tons, occur on Orange County beaches. The most abundant items were pre-production plastic pellets, foamed plastics, and hard plastics. Debris density on the remote rocky shoreline was greater than that on high-use sandy beaches for most debris items. This finding partially reflects the periodic clean-up of high-use beaches by local municipalities, and also indicates that a high percentage of the observed debris was transported to the site from waterborne sources.

Keywords: beaches; debris; plastics; pellets; southern California; pollution monitoring.

Beaches along the southern California coast are used extensively for a variety of recreational purposes, attracting almost 150 million visitors annually (Schiff *et al.*, 1999). Recreational uses such as boating, swimming, surfing, sunbathing, and picnicking generate debris along the shoreline including food bags and wrappers, cups and utensils, trash bags, fast-food and other product containers, toys, fishing lures and floats, and plastic. In addition, southern California has the highest coastal population density of any area in the country (Culliton *et al.*, 1988), providing an additional source of debris via urban runoff and maritime disposal (including accidental spills).

Debris is one of the most highly visible expressions of human impact on the marine environment, which is one of the factors that has led to the popularity of public clean-up efforts along the shoreline (Ribic *et al.*, 1997). More than an aesthetic issue, debris can threaten marine mammals, birds, and turtles through ingestion and entanglement (Bjorndal *et al.*, 1994; Fowler, 1987; Robards, 1993; Ryan, 1987). Marine debris is also becoming a regulatory focal point. The Los Angeles Regional Water Quality Control Board recently implemented legal limitations, through the total maximum daily load (TMDL) process, on the amount of trash that local governments can allow to enter the ocean through storm drains.

Many studies have enumerated the types and amount of marine debris on beaches (Corbin and Singh, 1993; Garrity and Levings, 1993; Golik, 1997; Golik and Gertner, 1992; Lucas, 1992; Ross *et al.*, 1991; Ribic *et al.*, 1997; Walker *et al.*, 1997; Willoughby, 1986), and a few studies have quantified subsurface nearshore debris (June, 1990; Moore and Allen, 2000). Most of the debris data for beaches outside of the United States have been collected through systematic, scientifically rigorous studies, while most of the information within the United States has been derived from volunteer beach cleaning efforts. Although cleaning efforts are valuable for removing debris from beaches, they provide only semi-quantitative estimates of debris. Here we present the first study to quantitatively assess the types and amount of debris on the California coast, with a secondary objective of describing how debris differs among shoreline types.

Materials and Methods

Beach debris was surveyed and collected at 43 sites from Seal Beach to San Clemente, on the Orange County, California coast, between 2 August and 18 September 1998 (Fig. 1). Sites were selected using a stratified random design, stratified by shoreline type (rocky shoreline and sandy beach). Sample sites were randomly selected within the strata and a systematic component was overlayed to minimize clustering, following the sampling design used in the National Stream Survey (Overton, 1987). Each stratum was subdivided into a series of sections (each identified by a count variable) of like-strata joined together into a stratum line. A partition

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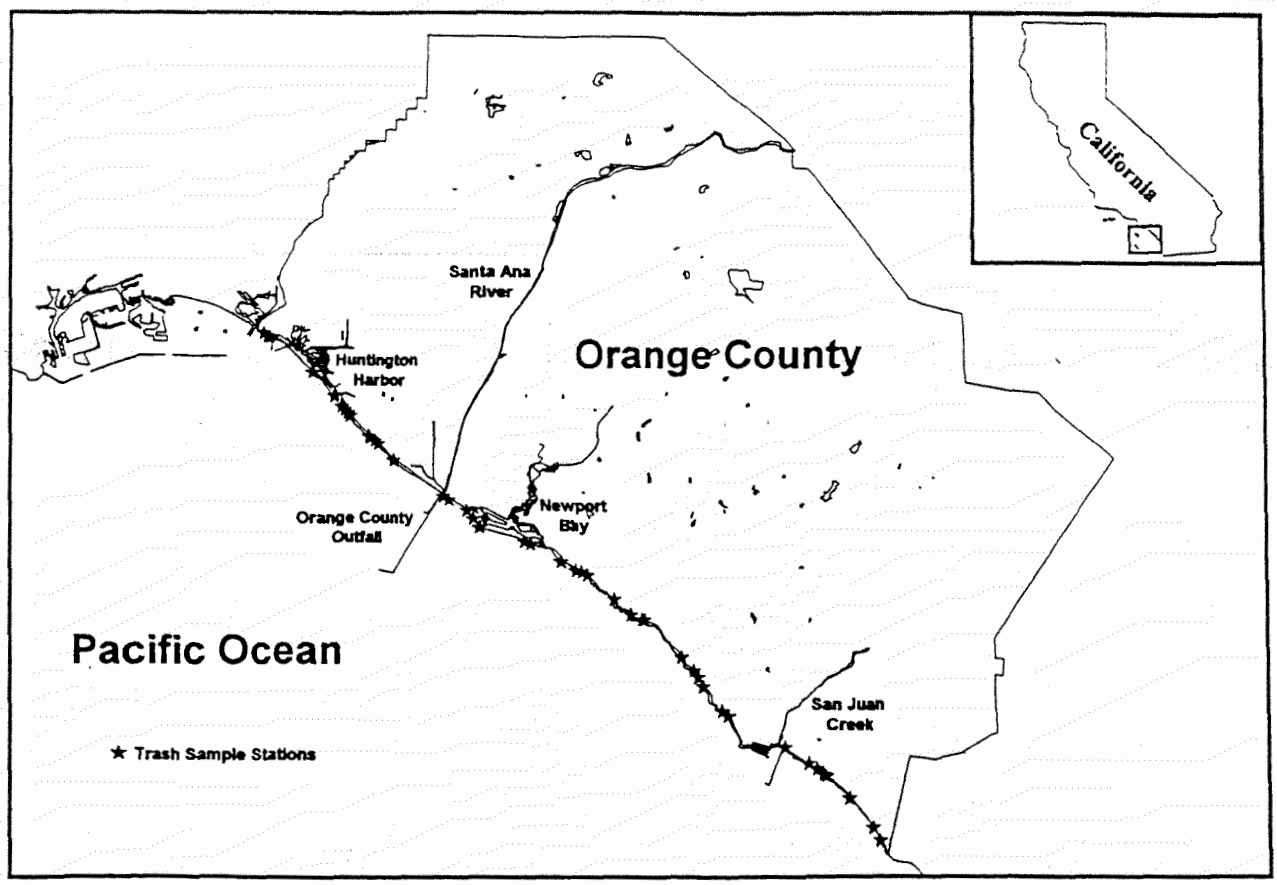

Fig. 1 Sample sites for the Orange County beach debris study, August 1998–September 1998.

was created for each stratum line, with the number of intervals in the partition equal to the sample size. The partition was placed over this stratum line by selecting a random starting point for the beginning of the first interval. Based on this starting point, the intervals were defined as consecutive equal-width lengths. A simple random sample of one point was then chosen from within each interval. Each point was translated back to the shoreline using the section count variable. The partition structure ensures systematic separation of the sampling, while the random selection of sites within partitions ensures an unbiased estimate of beach debris.

Each sample site was delineated as an area 22.9 m in length that extends from the water's edge to the first pavement or rocky cliff. All trash at the site was collected by at least three people walking systematically along transects to ensure that all areas within the sample site were examined. All debris was bagged and transported to the laboratory for identification and quantification. In addition, an 18.9 l bucket was used to sieve one bucket of sand at each site to quantify the small items that were undetectable by visual examination. In the laboratory, debris was sorted into the broad categories used by the Center for Marine Conservation during their Coastal Clean-up days (i.e., glass, metal, plastics, foamed plastics, rubber, paper, wood, and cloth). From each broad category, debris was further sorted into more specific subcategories (e.g., cups, plates, etc.), enumerated, and weighed. Within the specific categories, brand names were recorded, when possible, to establish cross-brand trends.

The total amount of debris along the Orange County coast was estimated by calculating a mean amount of trash for a 22.9 m segment within each strata and then weighting those means by the relative amount of shoreline distance in each strata. Estimates for smaller debris collected by sieving were calculated using a similar methodology, after estimating the number of meters from the water's edge to the first pavement or rocky cliff for each site then extrapolating the abundance for each sample site area.

Results

More than 106 million items, weighing approximately 12 metric tons, were estimated to occur along the Orange County shoreline (Table 1). Three categories of plastics (pre-production plastic pellets, foamed plastics, and hard plastics), accounted for 99% of the total abundance and 51% of the total weight. Cigarette butts were fourth in abundance and accounted for less than 1% of the total abundance and weight. Cigarettes, candy, fast-food products, beer, and other beverages were the most identified brand-related debris (Table 2). Marlboro®,

TABLE 1

Estimated total abundance and weight of trash on Orange County beaches, August 1998–September 1998.

Debris type	Estimated totals for Orange County	
	Abundance	Weight (kg)
Pre-production plastic pellets	105 161 101	2168
Foamed plastics	742 296	692
Hard plastics	642 020	3588
Cigarette butts	139 447	156
Paper	67 582	394
Wood	27 919	2066
Metal	23 500	1368
Glass	22 195	882
Rubber	10 742	371
Pet and bird droppings	9388	8
Cloth	5949	650
Other	10 363	182
Total	106 862 502	12 525

TABLE 2

Percent of total of top three brands in main brand categories collected on Orange County beaches, August 1998–September, 1998.

Brand name	Percent of total	Percent market share
Cigarette products		
Marlboro	62	32.3
Camel	7	4.6
Benson and Hedges	7	< 2.4
Candy products		
Starburst	16	na[a]
Snickers	13	na
Blow Pop	9	na
Fast food products		
Jack in the box	27	3.6
Carls Jr	19	1.9
KFC	12	< 0.9
Beer products		
Budweiser light	27	12.9
Budweiser	16	18.3
Corona	7	2.0
Drink products		
Coca Cola	16	20.6
Pepsi	15	14.2
Capri Sun	8	< 1.2

[a] na – not available.

Starburst®, Jack in the Box®, Budweiser Light®, and Coca Cola® all led in their respective categories.

Most of the plastics encountered were in the form of small pieces of plastic (Table 3). Foamed plastic pieces accounted for 88% of the total foamed plastics and hard plastic pieces accounted for 50% of the total hard plastics. Of the whole plastic items, food and beverage items were the most abundant.

The distribution of debris differed among shoreline types. Sandy beaches are eight times more abundant than rocky shoreline in Orange County, but most debris did not reflect this ratio (Table 4). Foamed and hard plastics, glass, rubber, and animal droppings all occurred at higher proportions on rocky beaches. Pre-production plastic pellets, paper, wood, and cloth all occurred at higher proportions on sandy beaches. Cigarette butts and metal were found at approximately equal ratios between beach types.

TABLE 3

Estimated total abundance of plastics on Orange County beaches, August 1998–September 1998.

Trash type	Abundance
Foamed plastics	
Foamed plastic pieces	652 639
Fast food containers	43 167
Other foamed plastics	25 415
Cups	10 595
Packaging material	9940
Plates	270
Meat trays	180
Buoys	90
Total	742 296
Plastics	
Plastic pieces	318 790
Caps and lids	88 548
Straws	84 990
Food bags and wrappers	58 394
Other plastic	48 799
Cups and utensils	9641
Other plastic bags	7164
Cigarette lighters	5810
Beverage bottles	4550
Trash bags	3729
Toys	2159
Buckets	1973
Rope	1848
Other bottles	1563
Milk and water bottles	1182
Diapers	1003
Strapping bands	449
6-pack holders	321
Fishing line	321
Tampon applicators	301
Fishing lures and floats	281
Oil and lube bottles	114
Light sticks	90
Total	642 020
Total plastics	1 384 316

Discussion

The most abundant item found on southern California beaches was pre-production plastic pellets, which are probably lost in transport from the raw material producers to the processors who mold the pellets into plastic products. The pellets, collected primarily through sieving the surface layers of sand, come in a variety of shapes (ovoid, cylindrical, etc.) and are typically less than 5 mm in diameter. Approximately one quadrillion of these pellets, representing 60 billion pounds of resin, are manufactured annually in the United States alone (USEPA, 1992). The presence of these pellets is not unique to US beaches (Gregory, 1977, 1978, 1983; Shiber, 1979, 1982). Gregory (1977, 1978) estimated that the number of these pellets on New Zealand beaches could possibly exceed 1000 t.

TABLE 4

Estimated total abundance of trash by beach type on Orange County beaches. August 1998–September 1998.

Debris type	Beach type		
	Sandy	Rocky	Sandy:Rocky ratio
Percent of shoreline	89	11	8:1
Pre-production plastic pellets	96 211 029	8 950 072	11:1
Foamed plastics	557 319	184 977	3:1
Hard plastics	424 257	217 763	2:1
Cigarette butts	124 422	15 025	8:1
Paper	64 729	2853	23:1
Wood	25 611	2308	11:1
Metal	20 468	3032	7:1
Glass	4055	18 140	1:4
Rubber	9039	1703	5:1
Pet and bird droppings	7217	2171	3:1
Cloth	5529	420	13:1
Other	10 300	63	163:1
Total	97 463 975	9 398 527	10:1

The relative distribution of brand-name products in the debris we collected largely reflects the product's relative market share. For example, we collected 10 times more Marlboro cigarette butts than any other brand, consistent with Marlboro's 32% market share. Similarly, Budweiser and Budweiser Light dominated the beer debris category, as they do in sales. One exception to the high correlation between brand-related debris quantity and market share was in the fast-food container category. Industry leader McDonalds constituted less than 10% of the total debris measured, while Jack in the Box accounted for nearly three times that level. Perhaps the geographic distribution of fast-food restaurants in relation to Orange County beaches was responsible for the discrepancy in the amount of fast-food product debris collected compared to the brand's respective market share.

Four major sources have been identified as pathways in the transport of debris to the Orange County shoreline: (1) littering by beachgoers, (2) wind currents from upland sources, (3) runoff from land-based activities, and (4) overboard disposal from boating activities (including accidental spills). Each of these sources requires a different management action to effect a reduction in beach debris. Although our study was not designed to differentiate sources, our data suggest that water-based sources (runoff and overboard disposal) were more important than direct littering or wind. One line of evidence for this is that plastic pellets were found in abundance on all shoreline areas and are unlikely to originate from littering or wind. The second line of evidence is the greater density of most debris items found on less-frequented rocky shoreline compared to the sandy beaches (Table 4). While this pattern was true for most debris, an exception was the greater amount of paper products, such as food wrappers, found on sandy beaches, suggesting that they were left by beachgoers.

The only previous quantification of debris on the Orange County shoreline was from data collected by volunteers during the annual California Coastal Clean-up Day. Their 1998 clean-up event occurred the week after the present survey was completed and their estimate of the amount of debris was 50 times lower than our data (Table 5). Moreover, our estimate for Orange County debris exceeded the California Coastal Clean-up Day estimate for the entire state.

The estimates provided by the two surveys differ for several reasons. First, the California Coastal Clean-up Day is conducted by volunteers whose purpose it is to clean the beach rather than to quantify debris. As a result, it is likely that the some of the debris collected during this event was not recorded. Second, the volunteers focus their cleaning efforts on a subset of the coastline, which excludes the rocky shoreline where 10% of the debris was encountered in the present study. Third, the California Coastal Clean-up Day event

TABLE 5

Comparison of abundance for the Orange County summer trash survey and Center for Marine Conservation 1998 California Coastal Clean-up Day.

Debris type	Summer Survey	Coastal Clean-up Day	
	Orange County	Orange County	California
Pre-production plastic pellets	105 161 101	–	–
Foamed plastics	742 296	8170	211 406
Hard plastics	642 020	10 860	382 380
Cigarette butts	139 447	6717	309 910
Paper	67 582	2504	133 335
Wood	27 919	720	27 136
Metal	23 500	1456	110 201
Glass	22 195	1033	94 333
Rubber	10 742	643	25 666
Pet and bird droppings	9388	–	–
Cloth	5949	317	10 620
Other	10 363	–	–
Total with pellets	106 862 502	32 420	1 304 987
Total without pellets	1 701 401	32 420	1 304 987

TABLE 6

Comparison of beach debris amounts between Coastal Clean-up Day volunteers and the Orange County beach debris follow-up study.

Trash type	Total abundance of beach debris			
	Sunset Beach		Salt Creek	
	CCD[a]	OC[b]	CCD	OC[b]
No. of volunteers	56	8	197	5
Total weight (kg)	62	48	184	16
Foamed plastics	313	19219	1057	6336
Hard plastics	1419	13658	1775	5667
Cigarette butts	222	9293	1646	2464
Paper	139	3133	711	1338
Wood	28	387	121	246
Metal	26	1126	244	2534
Glass	15	950	257	–
Rubber	67	282	157	387
Cloth	5	634	48	141
Total	2234	48682	6016	19113

[a] CCD – Coastal Clean-up Day.
[b] Orange County beach debris follow-up study abundances are estimates of trash found in 0.8 km based on a 22.9 m sample.

focuses on many of the popular, easily accessible beaches that are regularly cleaned by mechanical combers. Moreover, the clean-up events usually only cover an area 0.4–0.8 of a kilometer from their starting locations (Mark Patrick, County of Orange, Harbors, Beaches, and Parks, pers. comm.), rather than the whole beach.

Another variable that could partially account for the discrepancy in the two survey results is that volunteers traditionally focus on larger, more visible debris to the exclusion of small, undetectable debris. To assess the impact of this variable, two beach sites (Salt Creek Beach and Sunset Beach) were sampled using the same methods as the present study. Sampling occurred immediately after the 18 September 1999, California Coastal Clean-up Day. While more than 8000 pieces of debris were collected from these beaches as part of the clean-up effort, we estimated 67795 pieces remaining (Table 6). Most of the remaining items were small: the majority of large items, such as glass bottles, were effectively removed by the California Coastal Clean-up Day volunteers.

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