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 cleanup 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 cleanup 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 August 2 and September 18, 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 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 meters 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-liter 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 Cleanup 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-meter 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®, 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.

Discussion

The most abundant item found on southern California beaches was pre-production plastic pellets, which are probably lost in transport from the raw materials 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 (U.S. EPA, 1992). The presence of these pellets is not unique to U.S. 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 1,000 tons.

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 Cleanup Day. Their 1998 cleanup 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 Cleanup Day estimate for the entire state.

The estimates provided by the two surveys differ for several reasons. First, the California Coastal Cleanup 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 Cleanup Day event focuses on many of the popular, easily accessible beaches that are regularly cleaned by mechanical combers. Moreover, the cleanup events usually only cover an area 0.4 to 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 September 18, 1999, California Coastal Cleanup Day. While more than 8,000 pieces of debris were collected from these beaches as part of the cleanup effort, we estimated 67,795 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 Cleanup Day volunteers.

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Figure Captions

FIGURE 1. Sample sites for the Orange County beach debris study, August to September 1998.

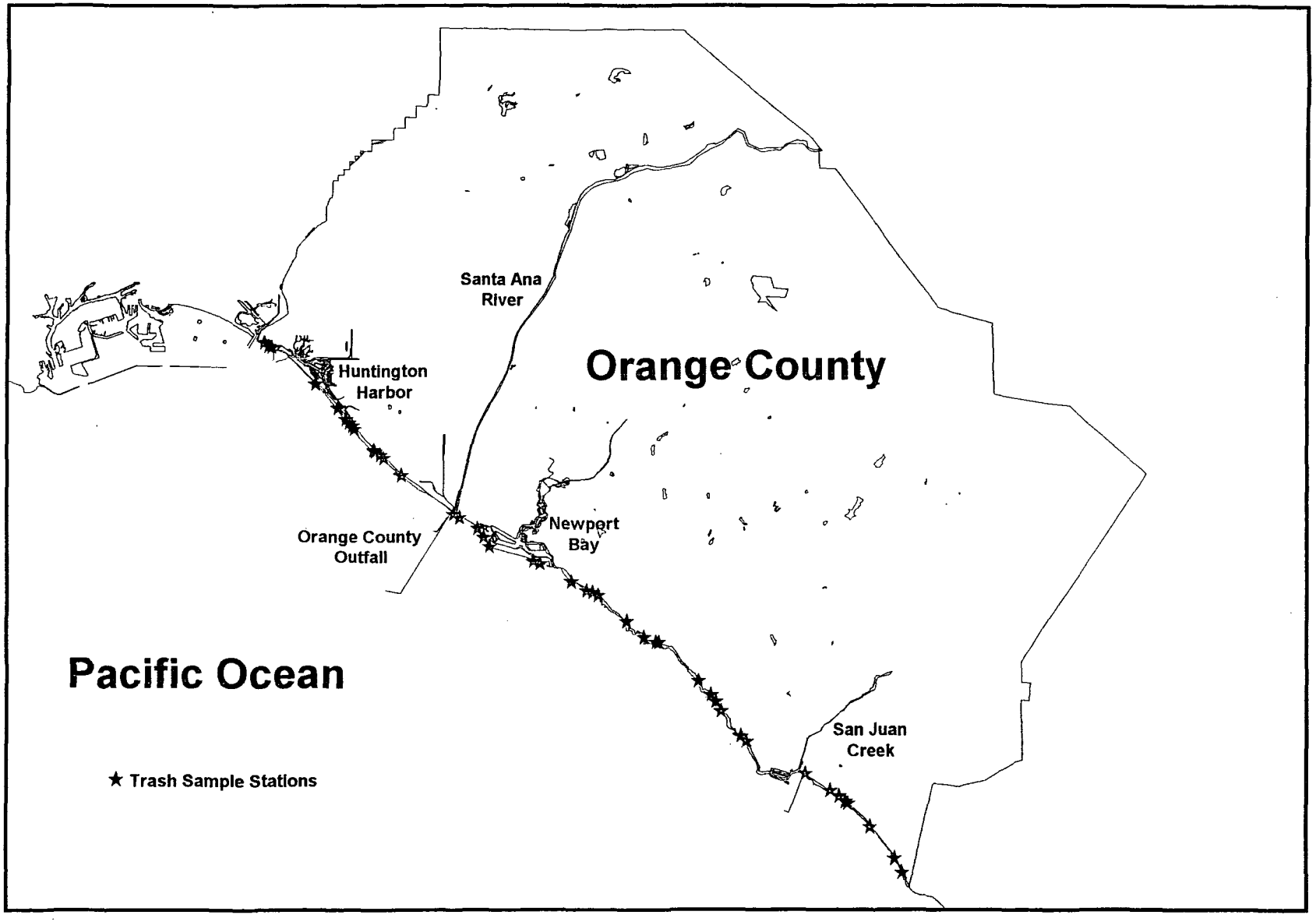
Santa Ana River
Orange County
Huntington Harbor
Orange County Outfall
Newport Bay
Pacific Ocean
San Juan Creek
★ Trash Sample Stations

TABLE 1

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

	Estimated Totals for Orange County	
Debris Type	Abundance	Weight (kg)
Pre-production plastic pellets	105,161,101	2,168
Foamed plastics	742,296	692
Hard plastics	642,020	3,588
Cigarette butts	139,447	156
Paper	67,582	394
Wood	27,919	2,066
Metal	23,500	1,368
Glass	22,195	882
Rubber	10,742	371
Pet and bird droppings	9,388	8
Cloth	5,949	650
Other	10,363	182
Total	106,862,502	12,525