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Trends and drivers of debris accumulation on Maui shorelines: Implications for local mitigation strategies

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ABSTRACT

Marine debris, particularly plastic, is an identified concern for coastal areas and is known to accumulate in large quantities in the North Pacific. Here we present results from the first study to quantify and compare the types and amounts of marine debris on Maui shorelines. Surveys were conducted monthly between May 2013 and December 2014, with additional daily surveys conducted on Maui's north shore during January 2015. Debris accumulation rates, loads, and sources varied between sites, with plastics being the most prevalent type of debris at all sites. Large debris loads on windward shores were attributed to the influence of the North Pacific Subtropical Gyre and northerly trade winds. Daily surveys resulted in a significantly higher rate of debris deposition than monthly surveys. The efficacy of local policy in debris mitigation showed promise, but was dependent upon the level of enforcement and consumer responsibility.

1. Introduction

Marine debris is a serious concern for coastal communities across the world. Not only does marine debris pose considerable threat to marine life, biodiversity, and ecosystems, but additionally impacts human health, safety, and local and national economies (Sheavly and Register, 2007; Gregory, 2009; Secretariat of the Convention on Biological Diversity (SCBD), 2012). Marine debris can further translate into loss of tourism revenue and recreation value, as well as affect coastal industries such as shipping and commercial fishing (Sheavly and Register, 2007; SCBD, 2012). Overall, plastics are considered the most common type of marine debris (Coe and Rogers, 1997; Derraik, 2002), with recent studies estimating the amount of plastic currently in the ocean at 5.25 trillion particles (Eriksen et al., 2014). Buoyant, lightweight, and slow to degrade, plastics have the ability to travel thousands of miles on ocean currents and can be deposited even on remote, uninhabited shorelines (Slip and Burton, 1991; Barnes, 2002; Morishige et al., 2007).

In the North Pacific Ocean, significant amounts of plastics and other debris have been discovered to accumulate in zones of regional surface current convergence that result from the clockwise rotation of the North Pacific Subtropical Gyre (STG) (Kubota, 1994; U.S. EPA, 2011; Howell et al., 2012; Law et al., 2014). Colloquially termed “garbage patches”, these areas have been identified in both the Eastern and Western North Pacific Ocean (Moore et al., 2001; Howell et al., 2012; Law et al., 2014). The Eastern and Western garbage patches themselves are linked by the Subtropical Convergence Zone (STCZ), a band of surface layer convergence that is located at the northern terminus of the STG (Pichel et al., 2007; U.S. EPA, 2011; Howell et al., 2012). Along with the garbage patches, the STCZ is known to concentrate marine debris (Pichel et al., 2007; U.S. EPA, 2011). In addition to surface currents, accumulation of debris on beaches is strongly influenced by wind speed and direction (Walker et al., 2006; Garcon et al., 2009; Eriksson et al., 2013).

The Hawaiian Archipelago is found within the STG and in close proximity to the STCZ, which likely contributes to the large amount of marine debris documented along Hawaiian shorelines (Ribic et al., 2012a). To date, the majority of marine debris accumulation studies in the Archipelago have focused on sites in the Northwestern Hawaiian Islands (NWHI), a string of uninhabited atolls stretching 1500 km northwest of the Main Hawaiian Islands (MHI) (Donohue et al., 2001; Henderson, 2001; Boland and Donohue, 2003; Dameron et al., 2007; Morishige et al., 2007; Ebbesmeyer et al., 2012; Ribic et al., 2012b). Despite the lack of large-scale human development, thousands of pounds of ocean-based marine debris have been removed from NWHI coastal areas (Donohue et al., 2001; Donohue, 2003).

Although fewer studies have been conducted on marine debris in the MHI, results indicate that debris accumulation is an issue (McDermid and McMullen, 2004; Corcoran et al., 2009; Cooper and Corcoran, 2010; Ribic et al., 2012a). Long-term data sets from O'ahu demonstrate that Hawaiian shorelines experience higher debris loads than coastal areas along the U.S. Pacific Coast, particularly ocean-based debris such as fishing nets and floats/buoys (Ribic et al., 2012a). Variation in debris loads on O'ahu were further linked to environmental drivers, particularly fluctuations in the regional El Nino Southern Oscillation cycle (ENSO) (Ribic et al., 2012a). Small-plastic debris has also been recorded on remote beaches in both the NWHI and MHI

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(McDermid and McMullen, 2004). Although studies have demonstrated that local debris inputs can contribute to local debris accumulation in Hawai'i (Carson et al., 2013), there is little understanding of how local environmental conditions influence accumulation rates and debris loads in the MHI. In addition, the impact of sampling interval on estimated accumulation rate remains to be explored, not only in the MHI but on shorelines worldwide (Ryan et al., 2009).

This is the first study to quantify the types and amounts of marine debris found on Maui shorelines and the main objectives were: 1) to identify localized environmental factors that influence marine debris accumulation on Maui beaches; 2) investigate the effects of temporal scale on accumulation rates; 3) characterize the type of marine debris most prevalent on Maui beaches; 4) evaluate the effectiveness of local marine debris policy and programs in Maui County. It was hypothesized that a higher debris load and rate of debris accumulation would occur at sites situated along Maui's windward coastline, due to the shoreline's orientation to trade winds and/or large wave events.

2. Methods

2.1. Site selection

Maui's climate is dominated by northeasterly trade winds experienced approximately 80% of the year, with stronger more consistent winds during the summer months (Sanderson, 1993). To account for environmental variations across the island, three study sites were chosen to represent shorelines from three of the four main geographical areas of the island: Site 1 (Pu'unoa Beach) (20.88421; −156.68681) on the West Shore, Site 2 (Po'olenalena Beach) (20.66310; −156.44164) on the South shore and Site 3 (Lower Waiehu Beach) (20.924177; −156.493389) on the North shore (Fig. 1). Study constraints prohibited the ability to select an East Maui site. Survey sites were chosen according to the criteria of the NOAA Marine Debris Shoreline Survey Field Guide (Opfer et al., 2012). Furthermore, sites were chosen that did not immediately front resorts, and best attempts were made to survey beaches that were less impacted by human traffic.

2.2. Site surveys

Monthly and daily site surveys were conducted following the accumulation survey protocol outlined in the NOAA Marine Debris Shoreline Survey Field Guide (Opfer et al., 2012). Prior to initial surveys, debris from each site was collected and removed to develop a baseline for accumulation. After the initial cleanup, all collected debris items were sorted and classified according to the following general categories: plastic, rubber, processed lumber, clothing/fabric, metal, large debris (>30 cm) which were further broken down into 66 subcategories. Only debris items measuring greater than 2.5 cm were collected. To determine the origin of debris, items were divided into three indicator debris categories based on their likely source. Categories were based on Ribic et al. (2012a) and are presented in Table 1.

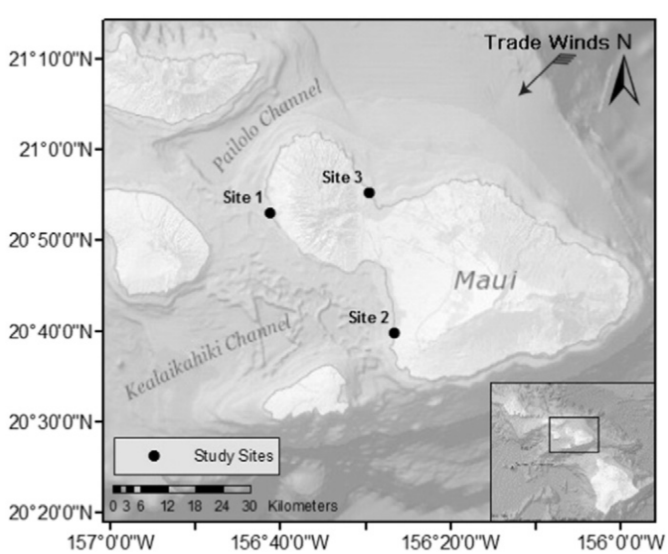

Fig. 1. Map showing the direction of prevailing trade winds and location of the three study sites on Maui. Site 1 = Pu'unoa Beach; Site 2 = Po'olenalena Beach; Site 3 = Lower Waiehu Beach.

2.2.1. Monthly accumulation

Monthly surveys took place at each site once every 28 days (±3 days) within ±30 min of low tide. Surveys were conducted within an established 100 m transect. Date, time, weather conditions, width of shoreline, and presence of storm activity within the past week were recorded for each survey. Each transect was traversed perpendicular to the water in 5 m increments, and covered the entire beach width from the water's edge to the vegetation line. Beach slope for each site was calculated using methods presented in Emery (1961). Surveys were conducted on a monthly basis from May 2013 through August 2014 for both Site 1 and Site 2 (17 total surveys) and from October 2013 through December 2014 for Site 3 (16 total surveys).

2.2.2. Daily accumulation

Site 3 was selected for additional daily accumulation surveys due to the large debris loads observed during monthly surveys. Accumulation surveys followed the same protocol as monthly surveys and were conducted daily for 28 consecutive days at Site 3 from January 2, 2015 through January 29, 2015.

2.3. Analysis

2.3.1. Monthly accumulation

A total of three monthly indices were calculated for each survey site to explain potential debris accumulation and retention. To summarize monthly wind speed and direction, a Relative Exposure Index (REI) was modified from Walker et al. (2006). A total of 8 wind directions determined by beach orientation were analyzed per site, each encompassing a total of 180°:

$$REI = \sum_{i=1}^{8} \frac{V_i P_i F_i}{100}$$

where V_i is the mean monthly wind speed (km h^{-1}) for wind directions categorized in 45° increments; P_i is the percent frequency from which the wind blew within each increment; and F_i is the fetch (USACERS, 1977) distance (km). Fetch lengths greater than or equal to 100 km were all set to 100 km and assumed to represent

Table 1
Indicator debris items classified by source category, as adapted from Ribic et al., 2012a.

Ocean-based	Land-based	General-source
Nylon rope/net fragments	Cigarette filters/cigars	Beverage bottles
Buoys/floats	Straws	Plastic bags
Fishing lures/line	Balloons	Packing straps
Spools	Fireworks	Bottle/container caps
Light sticks	Golf balls	Other jugs/containers
Oyster spacer tubes (large and small)*	Golf tees	
Hagfish traps*	Syringes	
	Personal care products	
	Flip-flops/slippers	
	Tires	
	Food wrappers	
	Clothing/shoes	

* Used only for analysis of daily accumulation debris.