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Geophysical features influence the accumulation of beach debris on Caribbean islands

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ABSTRACT

Anthropogenic beach debris was recorded during beach surveys of 24 Caribbean islands during April 2014–April 2016. Beach debris was classified according to material type (e.g., polystyrene) and item use (e.g., fishing). Geophysical features (substrate type, beach direction, and human accessibility) of sample sites were recorded in order to investigate their relationship with debris density. Results suggest the density of macro debris (items > 5 mm) is highest on uninhabited, sandy beaches facing a leeward direction. Higher debris quantities on inaccessible beaches may be due to less frequent beach clean ups. Frequently accessed beaches exhibited lower macro, but higher micro debris (items 1–5 mm) densities, possibly due to removal of macro debris during frequent beach clean ups. This suggests that while geophysical features have some influence on anthropogenic debris densities, high debris densities are occurring on all islands within the Caribbean region regardless of substrate, beach direction, or human accessibility.

1. Introduction

Plastics are lightweight, versatile, inexpensive and durable, and therefore the material of choice for a wide range of consumer and industrial products since its invention in the early 20th century (Thompson et al., 2009). Current plastic use is unsustainable, because many products are designed as single-use, and then discarded after being used for only a few minutes, yet persist in the environment for decades (EPA, 2016). Effective coordination of waste management and recovery of plastic materials is lacking on a global scale, and as a result, up to 12.7 million metric tonnes per year of discarded plastic ends up in the oceans (Jambeck et al., 2015).

Preventing marine debris is challenging due to its non-point source nature with almost endless entry points and diversity of materials (Ryan et al., 2009). Sources of debris can be either land- or marine-based (Thompson et al., 2009) with the latter defined as items discarded at sea – either intentionally or accidentally from commercial shipping vessels, fishing fleets, or recreational boating (Whiting, 1998). Land-based sources are more diverse, ranging from leakages in plastic production and intentional dumping to unintentional littering (Singh and Xavier, 1997; Siung-Chang, 1997). Once in the ocean, the non-biodegradable nature of plastic combined with wind and wave action, and photodegradation contribute to fragmentation of larger items into increasingly smaller pieces. Depending on their size, fragments are typically classified as either macro- (> 5 mm) or micro-plastics (1–5 mm), although additional size categories are sometimes used (e.g., nanoplastics < 1 mm; GESAMP, 2015; Hanvey et al., 2017). While many items that remain afloat will accumulate along oceanic convergence zones and in gyres of the major ocean basins (Coulter, 2010), including the subtropical latitudes of the Atlantic Ocean (Law et al., 2010), plastic debris is distributed from pole to pole (Thompson et al., 2009).

A review of beach debris by Barnes (2005) highlighted a gradient of debris accumulation from the equator to the poles that mirrors the approximate distribution of the human population. However, few studies have quantified beach debris, and its associated impacts, in remote locations (Vegter et al., 2014). The limited information available suggests that beach-based marine debris has increased over the past two decades, and may be many orders of magnitudes higher compared with the 1980–1990s (Barnes, 2005; Lavers and Bond, in press). On remote, tropical islands, the density of beach debris can be exceptionally high and often increases in relation to isolation (Duhec et al., 2015; McDermid and McMullen, 2004), likely a result of the

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accumulation of debris over time, rather than proximity to waste sources (Barnes, 2005). This poses an aesthetic issue, but is also worrying as plastic items deposited on beaches may alter beach characteristics, inflicting biological and economic consequences, for example, negatively impacting the breeding behaviour of turtles (Fujisaki and Lamont, 2016), or contributing to reductions in beach tourism (Jang et al., 2014).

In the Caribbean, monitoring of land-based sources of marine pollution was initiated in 1999 by the Caribbean Environmental Programme (CEP; UNEP, 1999). Since that time, sewage treatment policies and adoption of legally binding agreements regarding levels of acceptable waste (Cartagena Convention, Annex 3; Siung-Chang, 1997; UNEP, 1999) have not resulted in significant improvements to waste management, largely due to a lack of disposal facilities in ports, difficulty in finding appropriate sites for landfills, and significant inputs of land-based debris through major rivers, urban centres, and industries (Siung-Chang, 1997). As a result, a number of pollution hotspots have been identified in the Caribbean region, located primarily adjacent to urban centres, agricultural areas, and tourism sites (e.g., Ivar do Sul and Costa, 2007; Williams et al., 2016). The main distribution pathway for marine debris was speculated to be prevailing ocean currents and winds, with seasonal fluctuations in debris abundance due to stronger onshore winds in the dry season (Garrity and Levings, 1993; Hastenrath, 1976). The two main currents in the wider Caribbean region (WCR; i.e., geographic area including the Caribbean islands, the Caribbean Sea, and the coastlines of North, Central, and South America bordering the Caribbean Sea) are the Caribbean Current, which enters the Caribbean Sea near Grenada and originates in the Panama Gyre, and the Antilles Current, which flows northward and is sourced from the dominant Atlantic current systems (Jury, 2011).

To date, few studies have investigated the issue of marine debris in the Caribbean. Most were conducted more than two decades ago (Corbin and Singh, 1993; Ivar do Sul and Costa, 2007; Singh and Xavier, 1997), focus on individual islands/countries (e.g., de Scisciolo et al., 2016) with an overall lack of standard methodology for sampling which complicates cross study comparisons of debris densities (Ryan et al., 2009). Here we investigated the density, dominant type, and source of marine debris on the beaches of 24 islands across the Caribbean Sea in relation to their geophysical features and level of accessibility to visitors. A primary objective of this research was to provide a snapshot on the density of anthropogenic marine debris, including micro items, found on 'pristine' beaches across a relatively large geographic region.

2. Methods

2.1. Sampling locations

In total, 42 beaches across 24 islands from 5 nations were sampled during April 2014, February–March 2015, and March–April 2016 including the Bahamas (n = 12), British Virgin Islands (n = 1), Dominican Republic (n = 5), Grenada (n = 3), St. Vincent and the Grenadines (n = 10), Turks & Caicos Islands (n = 2), Cayman Islands (n = 6), Martinique (n = 3), and St. Eustatius (n = 1; Fig. 1). In 2016, volunteer 'citizen scientists' were invited to contribute data to this project and were provided with a detailed sampling protocol, thereby ensuring consistent data collection. The protocol explained the transect method (e.g., dimensions; details provided below), the differences between macro- and micro-plastics, and included an identification and definition guide for different categories of debris, and datasheet for recording marine debris on beaches.

2.2. Sampling design

Beach substrate was recorded as sandy, rocky, or mixed. Beach direction was defined as leeward or windward facing. Beaches were classified as windward when facing the dominant oceanographic currents that typically flow from the Atlantic Ocean into the WCR (i.e., windward beaches were those beaches located on the north and north-eastern side of islands). Approximately 60% (n = 26) of the beaches surveyed during this study faced a windward direction (leeward: n = 17).

Transects were established parallel to the water and along the high tide mark and measured 2 m × 20 m. For a small subset of transects, the length and width was adjusted to overcome challenges related to beach characteristics (e.g., the beach was too narrow). In areas of especially high plastic density, transect area was reduced to 20 m^2 (10 m × 2 m) in order to enable data collection within a reasonable time frame. On a subset of beaches, the density of micro-debris items was estimated within existing transects, or by establishing one quadrat (typically 10 × 10 cm) along the high tide line, which enabled detailed counts of all visible items. While the micro-debris surveys were limited in number (n = 11) and located primarily on beaches with high accessibility (n = 9), they provided valuable insight into the proportion of small debris items that are typically missed during traditional beach surveys that focus on macro pieces.

2.3. Anthropogenic debris classification

Anthropogenic debris items recorded on beaches were categorised as follows: plastic, glass, metal, polystyrene (e.g., foam), and wood. Plastic items were further subdivided into the following categories: disposable user items (e.g., straws, bottles), fishing related (e.g., rope, floats), film (e.g., bags, wrappers), unidentifiable fragments (micro- and macro-debris reported separately), clothing (e.g., shoes) and miscellaneous (e.g., toys, cosmetic items).

2.4. Debris density estimation

The density of marine debris items in each transect or quadrat was estimated as the total number of debris items (excluding micro-debris) per m^2 (± S.D.). The recorded number of debris items per transect was summed and then divided by transect area to generate the density per m^2. For later analysis the resulting density estimate for each transect was then calculated for a 40 m^2 transect area. We calculated the mean debris density per site and per country/territory (in cases when multiple beaches were sampled within the same country/island). For the quadrats, the density of micro-debris items was estimated separately, then scaled up to the corresponding density for a 20 × 2 m (40 m^2) transect and reported as items/40 m^2.

2.5. Statistical analysis

Statistical analysis was carried out in R 3.3.1 (R Core Team, 2016). To test the hypothesis that geophysical island features influence the abundance of debris on Caribbean beaches, factors considered in the models were split into two groups: geophysical island features (substrate, beach direction) and accessibility. Beach accessibility was defined as human presence and categorised as: inhabited (high), visited only (medium), and neither visited nor inhabited (low). As sites were surveyed only once, and our hypotheses concerned geophysical beach features, the year of collection was not included in our analysis. The uneven distribution of data was dealt with by calculating the number of debris pieces per 40 m^2 transect to produce count data that could be used in a Poisson generalized linear model. Parameter estimates are given with 95% confidence intervals.

3. Results

3.1. Density and type of anthropogenic debris on beaches

The abundance of macro debris on Caribbean beaches ranged from

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