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Debris size and buoyancy influence the dispersal distance of stranded litter

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ABSTRACT

Recent at sea surveys of floating macro-debris in the southeast Atlantic Ocean found that debris increases in size with distance from shore, suggesting that many smaller items, which dominate litter close to urban source areas, sink before dispersing far into the ocean. We test whether this pattern is evident in beach litter in the same region. Freshly stranded beach litter was collected at increasing distances (0 km, 100 km, 200 km and 2800 km) from Cape Town, a major urban litter source. Mean size and buoyancy of litter items increased significantly with distance from Cape Town. Size-specific sedimentation due to the ballasting effect of biofouling is a plausible explanation for the disappearance of smaller, less buoyant items. Our results provide further evidence that many low buoyancy items sink and support the hypothesis that size and buoyancy are strong predictors of dispersal distance for floating debris.

1. Introduction

Plastic has become a ubiquitous pollutant of the world's marine environments and is now recognised as a global threat to marine biodiversity (Moore, 2008). More than 500 marine animal species are affected by either entanglement or ingestion (Kühn et al., 2015) and floating plastic also poses more widespread ecological threats, such as the transport of alien species and modification of pelagic habitats (Gregory, 2009; Goldstein et al., 2012). Drifting plastic also absorbs waterborne chemical toxins, making them bio-available for entry into marine food chains (Rochman, 2015).

The distribution of plastic at sea is characterised by high geographic spatial variability (Barnes et al., 2009; Ryan et al., 2009; Cózar et al., 2014). On a macro-scale, floating debris accumulates along oceanic fronts and in the subtropical gyres (Moore et al., 2001; Martinez et al., 2009; Lebreton et al., 2012; Van Sebille et al., 2012), carried by combinations of Ekman drift, Stokes' drift and geostrophic surface currents (Kubota, 1994). For items with high windage, wind is a significant transport mechanism, often causing large protruding items to be carried along the surface in directions different to those of the prevailing currents (Duhec et al., 2015; Ryan, 2015). At a smaller scale, waves, buoyancy, friction and vertical mixing affect the size-distribution profiles of micro- and mesoplastics (Isobe et al., 2014; Reisser et al., 2014). In addition to different transport processes, volumes of debris in inshore waters are higher near areas of higher coastal populations and heavy industrial activity and are also influenced by differing waste management practices (Van Sebille et al., 2012; Jambeck et al., 2015). Natural factors such as coastal topography and vegetation can also influence the composition of plastic debris at both its point of entry and point of deposition (Martinez et al., 2009).

How these different transport mechanisms influence the dispersal dynamics of marine debris is poorly understood (Ryan et al., 2009). As the extent of the ecological threat posed by marine plastic debris becomes clearer, so too does the need to better understand these dynamics. Without improving our knowledge of the various mechanical, chemical and biological processes that affect the dispersal of plastic debris in the marine environment, our ability to understand and mitigate these threats is restricted. Understanding the transport vectors and the ultimate fate of microplastics is particularly important because their smaller size makes them available for interaction with biota at much lower trophic levels (Andrady, 2011).

More than half of the mass of plastics used in disposable applications such as packaging have densities lower than that of seawater (e.g. polyethylene and polypropylene; Andrady and Neal, 2009). As a result of their lightweight and durable nature, debris made from these plastics traditionally has been assumed to persist at the ocean surface for years and even decades (Martinez et al., 2009; Van Sebille et al., 2012). However, major discrepancies between the estimated amount of plastic entering the sea (4.8–12.7 million tonnes per year; Jambeck et al., 2015) and the estimated amount of plastic floating at the sea surface (250,000 tonnes; Eriksen et al., 2014) suggest that most plastic

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items either wash up on beaches or sink out from the sea surface. In particular, microplastics (<1 mm) and mesoplastics (~1–5 mm) are under-represented among samples of floating debris (Cózar et al., 2014; Eriksen et al., 2014). One mechanism that could remove floating debris from the sea surface is biofouling: the adherence of bacteria, diatoms, other algae and a diversity of sessile invertebrates (e.g. barnacles, bryozoans, mussels, etc.) onto submerged substrata (Ye and Andrady, 1991; Railkin, 2004; Lobelle and Cunliffe, 2011). Fouling takes place on all surfaces that come into contact with seawater, and is dependent on the amount of exposed surface area available for settlement (Wahl, 1989). In contrast, buoyancy is dependent on volume. Debris items with smaller volumes have greater surface area to volume ratios, making them more likely to be weighed down sooner by algae and other foulants (Ryan, 2015). Fouling is thus a possible mechanism that could explain the size-selective disappearance of smaller plastics from the sea surface.

A recent study of floating litter in the southeast Atlantic Ocean found an increase in the size of floating debris, an increase in the proportion of highly buoyant items (e.g. sealed bottles, floats and foamed plastics), and a decrease in the proportion of thin items such as plastic bags and flexible packaging which have high surface area to volume ratios, as one moved away from a major urban litter source area (Ryan, 2015). Our study investigates whether the same pattern occurs in freshly-stranded beach litter. Although some marine litter comes from ships and other marine-based sources, most is thought to originate from land-based sources (Ryan et al., 2009, Jambeck et al., 2015). By comparing the size and buoyancy composition of marine litter on urban and increasingly remote beaches in the same region, we can infer whether there is differential dispersal of floating debris linked to size and buoyancy. We predict that the mean size and buoyancy of beach litter would increase with distance from a major pollution source. Our results should also give some indication of the distances over which these processes occur.

2. Materials and methods

Sampling was conducted during September–October 2014 around Cape Town (34°S, 18°E), in South Africa's Western Cape Province, and at Tristan da Cunha and Gough Islands in the central South Atlantic Ocean (Fig. 1). Cape Town is the dominant pollution point source in the study area (although most debris reaching Tristan and Gough derives from South America; Ryan, 1987). The importance of Cape Town as a source area for marine litter is illustrated by accumulation rates at Milnerton, 10 km from the city centre (one of the urban beaches in this study, see below) being roughly five times greater than a similar beach at the northern edge of Table Bay, 35 km from the city centre (Ryan et al., 2014). Freshly stranded beach litter samples were collected from six sites around Cape Town: two 'urban' beaches, located within the metropolitan boundary, and four 'remote' beaches, located in nature reserves approximately 100 km and 200 km away from the city on the west and south coasts of the Western Cape (Fig. 1). One urban beach and two remote beaches were selected from each side of the city, giving two coastal transects, each comprising one urban beach, one intermediate remote beach (100 km) and one distant remote beach (200 km).

To assess the composition of litter at a really remote site, a sample of accumulated debris was also collected at Tristan da Cunha (37°S, 12°W) and Gough Island (40°S, 10°W) in the central South Atlantic, approximately 2800 km west of Cape Town.

The coastal beaches around Cape Town were all characterised by fine-grained sand with gentle to moderate gradients, all > 500 m long and all open to the sea, with no jetties or rocky outcrops. Only freshly stranded litter on wet sand was collected, with a lower size limit of

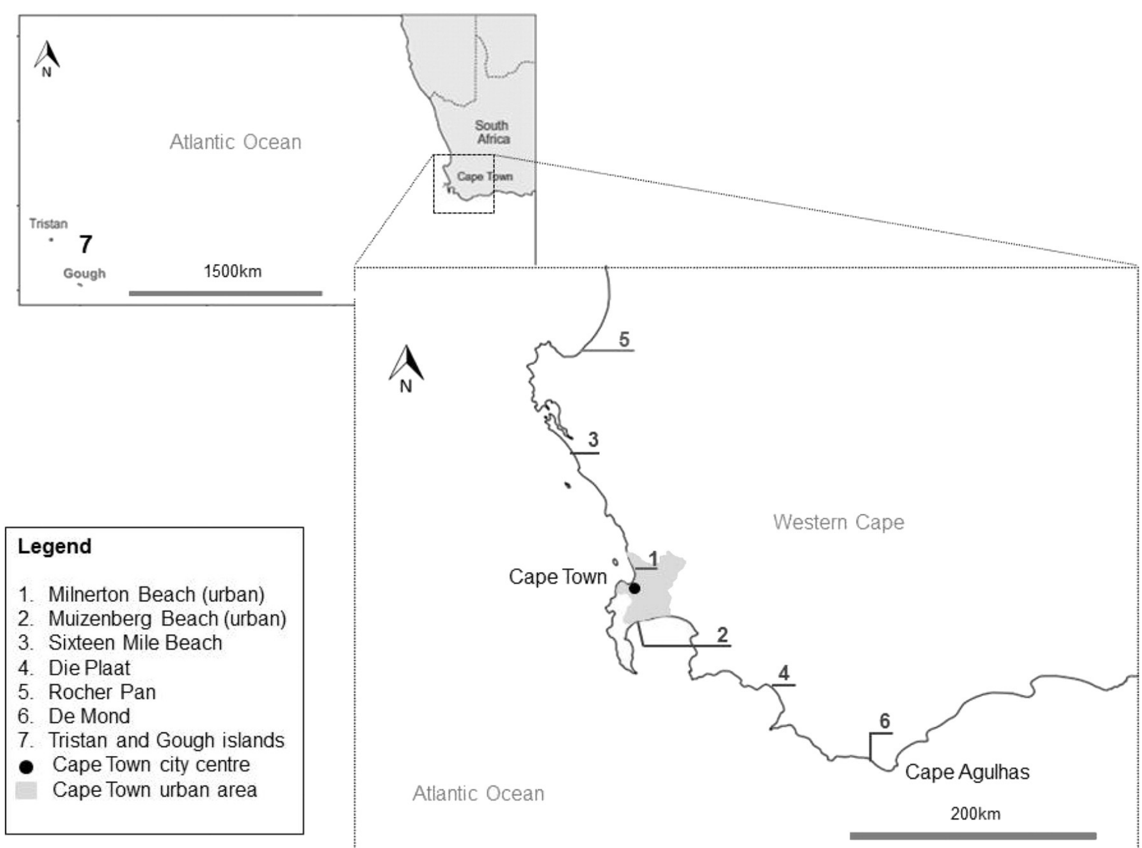

Fig. 1. Location of the six beach sampling sites in the Western Cape, South Africa and the seventh at Tristan da Cunha and Gough islands in the South Atlantic Ocean.

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