



Exceptional and rapid accumulation of anthropogenic debris on one of the world's most remote and pristine islands

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In just over half a century plastic products have revolutionized human society and have infiltrated terrestrial and marine environments in every corner of the globe. The hazard plastic debris poses to biodiversity is well established, but mitigation and planning are often hampered by a lack of quantitative data on accumulation patterns. Here we document the amount of debris and rate of accumulation on Henderson Island, a remote, uninhabited island in the South Pacific. The density of debris was the highest reported anywhere in the world, up to 671.6 items/m² (mean \pm SD: 239.4 \pm 347.3 items/m²) on the surface of the beaches. Approximately 68% of debris (up to 4,496.9 pieces/m²) on the beach was buried <10 cm in the sediment. An estimated 37.7 million debris items weighing a total of 17.6 tons are currently present on Henderson, with up to 26.8 new items/m accumulating daily. Rarely visited by humans, Henderson Island and other remote islands may be sinks for some of the world's increasing volume of waste.

Henderson Island | Pitcairn Island Group | South Pacific Gyre | marine debris | plastic pollution

Since the beginning of its mass manufacture in the 1950s, the annual production of plastic has increased from 1.7 million tons in 1954 to 311 million tons in 2014 (1). Because plastic is very durable and most is not recycled (2), accidentally or intentionally littered items eventually enter our waterways. Here, plastic's buoyancy facilitates its transport by currents and wind throughout the world's oceans, persisting for decades and breaking into increasingly smaller pieces as a result of physical abrasion from wave action or photodegradation (3). This relatively new but permanent aspect of the marine environment is now ubiquitous in the world's oceans, even in the most remote locations, far from metropolitan and populated areas (4, 5). The surface layer of the world's oceans now contains more than five trillion items, mostly microplastics (<5 mm) (6). This proliferation of debris in our oceans has led to the recognition of plastic pollution as a major global environmental issue (7).

The significant quantities of plastic in the ocean, although widespread, concentrate in defined areas, such as oceanic convergence zones (8) and ocean gyres (9), reaching densities as high as 890,000 pieces/km² (6). The plastic from these gyres likely poses a significant threat to the wildlife inhabiting these waters and the islands on their periphery (e.g., through dispersal of colonizing species) (10). However, few data are available because of the remote nature of the gyres and islands and the species within them, and the fate of plastic pollution in the marine environment generally is poorly known.

An improved understanding of the abundance, diversity, and sources of plastic is required to mitigate the plastic pollution, and there are a number of recognized ways to quantify these factors (11). They include quantifying plastic directly through at-sea trawl data (12) or indirectly by studying interactions with wildlife, e.g., frequency of ingestion or entanglement (13). For example, more than 200 species are now known to be at risk from the ingestion of plastic (14, 15), with evidence that some species

exhibit preferences for certain colors or types of plastic while foraging at sea (16, 17). Importantly, beach surveys provide similar and often complementary data on sources, patterns, and trends in the abundance and sources of marine plastic (18, 19). Examining the accumulation of plastic pollution on islands, particularly remote, uninhabited islands, can provide unique insights (11, 20).

Here, we present the results of a comprehensive survey of beach plastic in a UNESCO World Heritage site, Henderson Island, in the Pitcairn Group, South Pacific Ocean. Henderson Island is uninhabited and is very remote, with no major terrestrially based industrial facilities or human habitations within 5,000 km. Because there are no significant local sources of pollution, all anthropogenic debris on the island is derived from the global disposal and dispersal of waste. Here we summarize the limited data available for remote, uninhabited islands and provide quantitative data on the accumulation of debris on Henderson Island to highlight the utility of comprehensive beach surveys as reliable proxies for the state of the world's oceans.

Results

The density of surface debris ranged from 0.35–1.05 items/m² in the beach embayment forest (hereafter “beach-back”) and 20.5–671.6 items/m² on beaches (Table 1; also see *SI Results*). The density of debris buried to a depth of 10 cm within quadrats ranged from 53.1–4,496.9 pieces/m² on North and East Beaches (Table 1). The total number of visible and buried debris items estimated to be present on Henderson Island was 37,661,395 items weighing a total of 17,601 kg; the estimated mass of buried

Significance

The isolation of remote islands has, until recently, afforded protection from most human activities. However, society's increasing desire for plastic products has resulted in plastic becoming ubiquitous in the marine environment, where it persists for decades. We provide a comprehensive analysis of the quantity and source of beach-washed plastic debris on one of the world's remotest islands. The density of debris was the highest recorded anywhere in the world, suggesting that remote islands close to oceanic plastic accumulation zones act as important sinks for some of the waste accumulated in these areas. As global plastic production continues to increase exponentially, it will further impact the exceptional natural beauty and biodiversity for which remote islands have been recognized.

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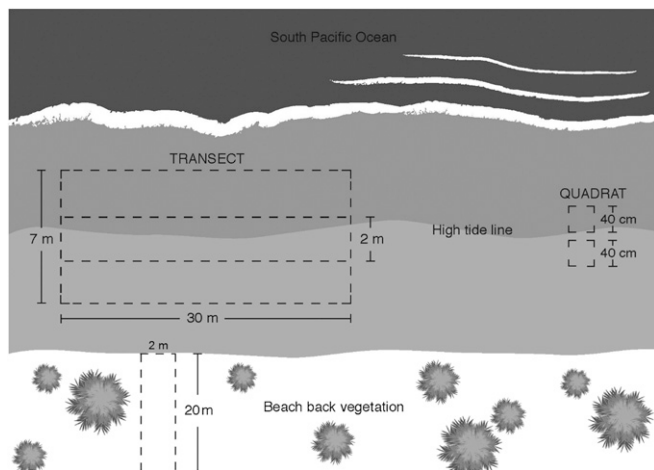


Fig. 2. Schematic drawing (not to scale) of the sampling design used to quantify debris on Henderson Island's beaches.

sources of debris (e.g., fishing boats) can be more important sources. Asian and South American sources of plastic on Henderson may reflect fishing activity in the surrounding waters

(Table S4) (30, 31); fishing-related items (e.g., buoys) accounted for 7.7% of items recorded (Table S4). The high frequency of items from South America (27.3% of identifiable items) (Table S5) also may result from Henderson's position in the South Pacific gyre (9). This current flows in an anticlockwise direction, after traveling north along the coast of South America, transporting coastal waste to the island (Fig. 1) (32). Remote islands off Chile and their adjacent waters contain high densities of beach plastic (Table S2), primarily fishing gear (33), suggesting that this pattern is widespread throughout the region.

Plastic debris on beaches creates a physical barrier, contributing to a reduction in the number of sea turtle laying attempts (Henderson Island is the only known nesting site in the Pitcairn Group) (Fig. 3A) (34, 35), lowered diversity of shoreline invertebrate communities (36), and increased hazard of entanglement for coastal-nesting seabirds (37, 38). The presence of debris on beaches therefore negatively impacts marine biodiversity, particularly on remote islands where significant volumes of debris accumulate and where prevention or mitigation is extremely challenging and costly and requires considerable time.

Conclusions

Changes in the frequency of wildlife ingestion of or entanglement in debris are often used as an indicator of pollution in the



Fig. 3. (A) Plastic debris on East Beach of Henderson Island. Much of this debris originated from fishing-related activities or land-based sources in China, Japan, and Chile (Table S5). (B) Plastic items recorded in a daily accumulation transect along the high tide line of North Beach. (C) Adult female green turtle (*Chelonia mydas*) entangled in fishing line on North Beach. (D) One of many hundreds of purple hermit crabs (*Coenobita spinosa*) that make their homes in plastic containers washed up on North Beach.

marine environment (39–41). Globally, the number of species known to interact negatively with marine debris has increased 49% in <20 y (14), with >55% of the world's seabird species [including two species from Henderson Island (42)] currently at risk (14). Combined with beach surveys, these data suggest that the quantity of anthropogenic debris in our oceans is increasing (3, 24).

Although detrimental impacts are observed and suspected across all levels of the marine ecosystem (43, 44), the true magnitude and fate of this pollution are often unclear because data are insufficient or incomplete (e.g., the lack of repeated sampling at sea). The quantity of floating debris in some areas of the oceans may be declining, potentially “lost” to other as-yet undetermined sinks in the marine environment (6, 39, 45). The end point, or removal mechanism, for some of this plastic likely includes remote islands such as Henderson, which have become reservoirs for the world's waste. The 17.6 tons of anthropogenic

debris estimated to be present on Henderson Island account for only 1.98 seconds' worth of the annual global production of plastic (46). As global plastic production continues to increase exponentially (47), it will further impact the exceptional natural beauty and biodiversity for which this island and many other UNESCO World Heritage Sites have been recognized.

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