

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

Jennifer L. Lavers<sup>a,b,1</sup> and Alexander L. Bond<sup>b</sup>

<sup>a</sup>Institute for Marine and Antarctic Studies, University of Tasmania, Battery Point, TAS 7004, Australia; and <sup>b</sup>Centre for Conservation Science, Royal Society for the Protection of Birds, Sandy, Bedfordshire SG19 2DL, United Kingdom

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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/m<sup>2</sup> (mean  $\pm$  SD: 239.4  $\pm$  347.3 items/m<sup>2</sup>) on the surface of the beaches. Approximately 68% of debris (up to 4,496.9 pieces/m<sup>2</sup>) 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/km<sup>2</sup> (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/m<sup>2</sup> in the beach embayment forest (hereafter “beach-back”) and 20.5–671.6 items/m<sup>2</sup> 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/m<sup>2</sup> 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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<sup>1</sup>To whom correspondence should be addressed. Email: Jennifer.Lavers@utas.edu.au.

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**Table 1.** Mean density (items/m<sup>2</sup> ± SD) of plastic debris items recorded in transects and quadrats on Henderson Island

| Site        | Mean recorded density (items/m <sup>2</sup> ) |             |                   | Estimated debris items |          |            |          |            |          | Estimated island total |          |
|-------------|---|-------------|-------------------|------------------------|----------|------------|----------|------------|----------|------------------------|----------|
|             | Beach   | Beach-back  | Buried            | Beach                  |          | Beach-back |          | Buried     |          | Number                 | Mass, kg |
|             |   |             |                   | Number                 | Mass, kg | Number     | Mass, kg | Number     | Mass, kg |                        |          |
| North Beach | 30.3 ± 13.8                                   | 0.50 ± 0.19 | 104.7 ± 58.0      | 812,116                | 2,985    | 21,000     | 3,176    | 6,800,936  | 97       | 7,634,052              | 4,744    |
| East Beach  | 239.4 ± 374.3                                 | 0.94 ± 0.12 | 1,286.7 ± 1,559.8 | 3,053,901              | 12,611   | 35,530     | 2,961    | 26,937,912 | 1,079    | 30,027,343             | 12,857   |
| Total       |   |             |                   | 3,866,017              | 15,597   | 56,530     | 6,137    | 33,738,848 | 1,176    | 37,661,395             | 17,601   |

Items include surface items on the beach and beach-back and items buried on the beach to a depth of 10 cm. Estimated total debris is based on mean mass, density, and dimensions for each beach.

debris items (1,176 kg) (Table 1) accounted for only a small proportion (0.07%) of the total, because the majority of buried items (65.5%) were <5 mm. Each day, 17–268 new items washed up on a 10-m section of North Beach, representing a daily accumulation rate of 1.7–26.8 items/m.

## Materials and Methods

**Study Site.** Henderson Island (4,308 ha, 9 × 5 km; 24°20'S, 128°19'W), one of four islands belonging to the Pitcairn Group, is a remote, uninhabited island in the South Pacific Ocean. The nearest settlement is Pitcairn Island, 115 km to the west and home to ~40 residents (Fig. 1). Henderson Island is surrounded by a fringing limestone reef up to 75 m wide (21), with beaches composed of fine to coarse white sand, pebbles, shells, and coral rubble. The predominant wind and current direction is from the northeast (Fig. 1) (21). Henderson Island is located on the western boundary of the South Pacific Gyre, a known plastic-accumulation zone (Fig. 1) (22).

**Sample Collection and Calculation of Accumulated Debris.** Micro- (2–5 mm) and macrodebris (≥5 mm) items, including plastic, glass, wood, and metal items, were sampled along the North (2.1 km long) and East (1.9 km long) Beaches of Henderson Island from 2015 May 29–August 15. Because of the dynamic nature of the marine environment and a number of challenging island features, we used three different transect and quadrat designs aimed at providing specific types of data (Fig. 2 and *SI Materials and Methods*). We sampled surface beach debris along five 30-m transects and 10 20-m transects in the beach-back. Buried debris (0–10 cm) was sieved from all sediment excavated in 10 0.4 × 0.4 m quadrats. Plastic accumulation was sampled along a 10 × 0.2 m transect centered on the high tide line on North Beach for six consecutive days. To extrapolate the total amount of debris on Henderson Island, we multiplied the mean surface densities and mean buried volumetric

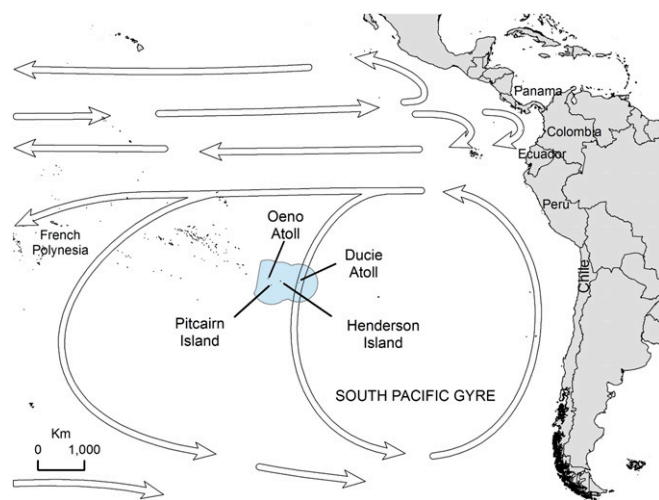
densities by total beach area and added the debris from a highly polluted area separately (*SI Materials and Methods*). All debris items (≥2 mm on beaches and ≥5 mm in the beach-back) encountered on sample transects or quadrats were counted, weighed, and sorted by type and color (see *SI Materials and Methods* for categories). All values are presented as mean ± SD.

## Discussion

We enumerated >53,100 anthropogenic debris items within transects, resulting in a minimum estimate of 37.7 million pieces of plastic debris weighing 17.6 tons on the sandy beaches of Henderson Island in 2015 (Table 1). Although alarming, these values underestimate the true amount of debris, because items buried >10 cm below the surface and particles <2 mm (<5 mm in the beach-back area) and debris along cliff areas and rocky coastlines could not be sampled. Small items are numerically dominant among all debris, with microplastics accounting for 55% of items floating in surface waters of the South Pacific Ocean (22) and 61.6% of items recorded in beach transects on Henderson Island (Table S1). In April and November 1991, “frighteningly large” amounts of beach debris were recorded on uninhabited Ducie and Oeno Atolls, at densities of 0.12 and 0.35 pieces/m<sup>2</sup>, respectively (see Table S2) (23). Twenty-five years later, the density of debris on neighboring Henderson Island is 200–2,000× higher (Fig. 3A and Table 1). Given that these islands are in the same group and experience similar oceanic conditions, their plastic densities are likely to be similar. If so, debris on Henderson Island has increased by 6.6–79.9%/y. The remote and isolated nature of Henderson Island means the standing stock of debris has not been affected by previous clean-up efforts or local land-based sources. The increase in debris on this isolated island therefore mirrors the long-term accumulation and the increased abundance of debris in our oceans (6, 11). Information on trends in the abundance of debris at sea are lacking (but see refs. 8 and 24), largely because of the currently prohibitive cost of offshore sampling, so beach-based surveys are a valuable source of information.

A range of factors influence the abundance of beach debris, including local currents, beach topography, and weather conditions, which can result in burial (11, 20). Few studies of debris on beaches have included buried material, even though it has been shown to comprise the majority of debris (~65%) (Table S3) (25, 26). We found that 68% of all debris on Henderson was buried (Table 1). Data on beach debris accumulation rates are similarly rare (Table S2). We estimated a minimum of 3,570 debris items were deposited on North Beach daily ( $13,316 \pm 10,094$  items·km<sup>-1</sup>·d<sup>-1</sup>), five orders of magnitude greater than the accumulation rates reported elsewhere (Table S2). The daily accumulation accounts for around a quarter of the total debris present on the beach (Table 1) and highlights the dynamic process of the deposition of new debris, movement of debris already present on the beach, burial of existing debris, and removal of debris by outgoing waves and tides (26).

Land-based sources (e.g., storm drains) represent ~80% of plastic inputs to the ocean (27). However, on oceanic islands (23, 28) and undeveloped continental beaches (29), marine-based



**Fig. 1.** The location of Henderson Island. The boundary of the Pitcairn Islands Exclusive Economic Area is shown in light blue. Arrows indicate the direction of major oceanic currents and the South Pacific Gyre.



**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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1. PlasticsEurope (2015) *Plastics - the Facts 2015: An Analysis of European Plastics Production, Demand and Waste Data* (PlasticsEurope Market Research Group, Brussels).
2. Hopewell J, Dvorak R, Kosior E (2009) Plastics recycling: Challenges and opportunities. *Philos Trans R Soc Lond B Biol Sci* 364:2115–2126.
3. Barnes DKA, Galgani F, Thompson RC, Barlaz M (2009) Accumulation and fragmentation of plastic debris in global environments. *Philos Trans R Soc Lond B Biol Sci* 364: 1985–1998.
4. Barnes DK, Walters A, Gonçalves L (2010) Macroplastics at sea around Antarctica. *Mar Environ Res* 70:250–252.
5. Bergmann M, Klages M (2012) Increase of litter at the Arctic deep-sea observatory HAUSGARTEN. *Mar Pollut Bull* 64:2734–2741.
6. Eriksen M, et al. (2014) Plastic pollution in the world's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. *PLoS One* 9:e111913.
7. United Nations Environment Programme (2014) Plastic debris in the ocean. *Year Book 2014: Emerging Issues in Our Global Environment* (United Nations Environment Programme, Nairobi), pp 46–53.
8. Law KL, et al. (2010) Plastic accumulation in the North Atlantic subtropical gyre. *Science* 329:1185–1188.
9. Lebreton LCM, Greer SD, Borrero JC (2012) Numerical modelling of floating debris in the world's oceans. *Mar Pollut Bull* 64:653–661.
10. Zettler ER, Mincer TJ, Amaral-Zettler LA (2013) Life in the “plastisphere”: Microbial communities on plastic marine debris. *Environ Sci Technol* 47:7137–7146.
11. Ryan PG, Moore CJ, van Franeker JA, Moloney CL (2009) Monitoring the abundance of plastic debris in the marine environment. *Philos Trans R Soc Lond B Biol Sci* 364:1999–2012.
12. Reisser J, et al. (2014) The vertical distribution of buoyant plastics at sea. *Biogeosciences Discuss* 11:16207–16226.
13. Barnes DKA, Milner P (2005) Drifting plastic and its consequences for sessile organism dispersal in the Atlantic Ocean. *Mar Biol* 146:815–825.
14. Gall SC, Thompson RC (2015) The impact of debris on marine life. *Mar Pollut Bull* 92: 170–179.
15. Vegter AC, et al. (2014) Global research priorities for the management and mitigation of plastic pollution on marine wildlife. *Endanger Species Res* 25:225–247.
16. Lavers JL, Bond AL (2016) Selectivity of flesh-footed shearwaters for plastic colour: Evidence for differential provisioning in adults and fledglings. *Mar Environ Res* 113:1–6.
17. Ryan PG (2008) Seabirds indicate changes in the composition of plastic litter in the Atlantic and south-western Indian Oceans. *Mar Pollut Bull* 56:1406–1409.
18. Ivar do Sul JA, Santos IR, Friedrich AC, Matthiensen A, Fillmann G (2011) Plastic pollution at a sea turtle conservation area in NE Brazil: Contrasting developed and undeveloped beaches. *Estuaries Coasts* 34:814–823.
19. Lee RF, Sanders DP (2015) The amount and accumulation rate of plastic debris on marshes and beaches on the Georgia coast. *Mar Pollut Bull* 91:113–119.
20. Barnes DKA (2005) Remote islands reveal rapid rise of southern hemisphere, sea debris. *Sci World J* 5:915–921.
21. Irving RA (1995) Nearshore bathymetry and reef biotopes of Henderson Island, Pitcairn Group. *Biol J Linn Soc Lond* 56:309–324.
22. Eriksen M, et al. (2013) Plastic pollution in the South Pacific subtropical gyre. *Mar Pollut Bull* 68:71–76.
23. Benton TG (1995) From castaways to throwaways: Marine litter in the Pitcairn Islands. *Biol J Linn Soc Lond* 56:415–422.
24. Thompson RC, et al. (2004) Lost at sea: Where is all the plastic? *Science* 304:838.
25. Kusui T, Noda M (2003) International survey on the distribution of stranded and buried litter on beaches along the Sea of Japan. *Mar Pollut Bull* 47:175–179.
26. Williams AT, Tudor DT (2001) Litter burial and exhumation: Spatial and temporal distribution on a cobble pocket beach. *Mar Pollut Bull* 42:1031–1039.
27. Nollkaemper A (1994) Land-based discharges of marine debris - from local to global regulation. *Mar Pollut Bull* 28:649–652.
28. do Sul JA, Spengler A, Costa MF (2009) Here, there and everywhere. Small plastic fragments and pellets on beaches of Fernando de Noronha (Equatorial Western Atlantic). *Mar Pollut Bull* 58:1236–1238.
29. Santos IR, Friedrich AC, Wallner-Kersanach M, Fillmann G (2005) Influence of socio-economic characteristics of beach users on litter generation. *Ocean Coast Manage* 48:742–752.
30. Parks and Wildlife Service (2014) *Evaluation Report: Macquarie Island Pest Eradication Project, August 2014* (Department of Primary Industries, Parks, Water and Environment, Hobart, TAS, Australia).
31. Adams T, Langley A (2005) *The Potential for Development of Fisheries in the Pitcairn EEZ* (Secretariat of the Pacific Community Marine Resources Division, Noumea, New Caledonia), pp 1–79.
32. Martinez E, Maamaatuaiahutapu K, Taillandier V (2009) Floating marine debris surface drift: Convergence and accumulation toward the South Pacific subtropical gyre. *Mar Pollut Bull* 58:1347–1355.
33. Thiel M, et al. (2011) Anthropogenic litter in the SE Pacific: An overview of the problem and possible solutions. *Journal of Integrated Coastal Zone Management* 11: 115–134.
34. Fujisaki I, Lamont MM (2016) The effects of large beach debris on nesting sea turtles. *J Exp Mar Biol Ecol* 482:33–37.
35. Brooke MdeL (1995) Seasonality and numbers of green turtles *Chelonia mydas* nesting on the Pitcairn islands. *Biol J Linn Soc Lond* 56:325–327.
36. Uneputty P, Evans SM (1997) The impact of plastic debris on the biota of tidal flats in Ambon Bay (eastern Indonesia). *Mar Environ Res* 44:233–242.
37. Lavers JL, Hodgson JC, Clarke RH (2013) Prevalence and composition of marine debris in Brown Booby (*Sula leucogaster*) nests at Ashmore Reef. *Mar Pollut Bull* 77:320–324.
38. Votier SC, Archibald K, Morgan G, Morgan L (2011) The use of plastic debris as nesting material by a colonial seabird and associated entanglement mortality. *Mar Pollut Bull* 62:168–172.
39. van Franeker JA, Law KL (2015) Seabirds, gyres and global trends in plastic pollution. *Environ Pollut* 203:89–96.
40. Lavers JL, Bond AL, Hutton I (2014) Plastic ingestion by Flesh-footed Shearwaters (*Puffinus carneipes*): Implications for fledgling body condition and the accumulation of plastic-derived chemicals. *Environ Pollut* 187:124–129.
41. Lavers JL, Bond AL (2016) Ingested plastic as a route for trace metals in Laysan Albatross (*Phoebastria immutabilis*) and Bonin Petrel (*Pterodroma hypoleuca*) from Midway Atoll. *Mar Pollut Bull* 110:493–500.
42. Imber MJ, Jolly JN, Brooke MdeL (1995) Food of three sympatric gadfly petrels (*Pterodroma* spp.) breeding on the Pitcairn Islands. *Biol J Linn Soc Lond* 56:233–240.
43. Browne MA, et al. (2015) Linking effects of anthropogenic debris to ecological impacts. *Proc Biol Sci* 282:20142929.
44. Rochman CM, et al. (2016) The ecological impacts of marine debris: Unraveling the demonstrated evidence from what is perceived. *Ecology* 97:302–312.
45. Cózar A, et al. (2014) Plastic debris in the open ocean. *Proc Natl Acad Sci USA* 111: 10239–10244.
46. Rochman CM, et al. (2013) Policy: Classify plastic waste as hazardous. *Nature* 494: 169–171.
47. PlasticsEurope (2013) *Plastics - the Facts 2013: An Analysis of European Plastics Production, Demand and Recovery for 2012* (PlasticsEurope Market Research Group, Brussels).
48. Waldren S, Florence J, Chepstow-Lusty AJ (1995) A comparison of the vegetation communities from the islands of the Pitcairn Group. *Biol J Linn Soc* 56:121–144.
49. Ribic CA, Sheavly SB, Klavitter J (2012) Baseline for beached marine debris on Sand Island, Midway Atoll. *Mar Pollut Bull* 64:1726–1729.
50. Merrell TR (1980) Accumulation of plastic litter on beaches of Amchitka Island, Alaska. *Mar Environ Res* 3:171–184.
51. Eriksson C, Burton H, Fitch S, Schulz M, van den Hoff J (2013) Daily accumulation rates of marine debris on sub-Antarctic island beaches. *Mar Pollut Bull* 66:199–208.
52. Bouwman H, Evans SW, Cole N, Choong Kwet Yive NS, Kylin H (2016) The flip-or-flop boutique: Marine debris on the shores of St Brandon's rock, an isolated tropical atoll in the Indian Ocean. *Mar Environ Res* 114:58–64.
53. Ryan PG (1987) The origin and fate of artefacts stranded on islands in the African sector of the Southern Ocean. *Environ Conserv* 14:341–346.
54. Convey P, Barnes D, Morton A (2002) Debris accumulation on oceanic island shores of the Scotia Arc, Antarctica. *Polar Biol* 25:612–617.
55. Benton TG (1991) Oceans of garbage. *Nature* 352:113.