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The use of anthropogenic marine debris as a nesting material by brown boobies (*Sula leucogaster*)

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ABSTRACT

Marine debris is pervasive worldwide, and affects biota negatively. We compared the characteristics of debris incorporated within brown booby (*Sula leucogaster*) nests throughout their pantropical distribution by assessing the type, colour and mass of debris items within nests and in beach transects at 18 sites, to determine if nests are indicators of the amount of debris in local marine environments. Debris was present in 14.4% of nests surveyed, with the proportion of nests with debris varying among sites (range: 0–100%). There was minimal overlap between the type or colour of debris found in nests and on adjacent beaches at individual sites. This suggests that brown boobies do not select debris uniformly across their distribution. We propose that the nests of brown boobies can be used as a sentinel of marine debris pollution of their local environment.

1. Introduction

Anthropogenic marine debris (hereafter 'debris') is one of the most recognised and pervasive environmental issues in marine ecosystems (Lippiatt et al., 2013; Provencher et al., 2017). Defined as any man-made solid material, debris is ubiquitous and rapidly increasing throughout the world's oceans (Barnes et al., 2009; Eriksen et al., 2014; Lavers and Bond, 2017). Due to its widespread and often patchy distribution, effective scientific research and monitoring is challenging and can be limited by resources, time, or geography (van der Velde et al., 2017; Zettler et al., 2017). When faced with these difficult conditions, ecological indicator, or 'sentinel', species are often used as a tool to gather data more effectively and communicate the health of ecosystems, providing unique insights that otherwise may be hard to gather (Dale and Beyeler, 2001).

As apex predators reliant on the marine environment, seabirds are used frequently as sentinels of ocean health (Cairns, 1987; Piatt et al., 2007). Documenting aspects of their behaviour, physiology, and population ecology can enhance our knowledge of oceanographic conditions, prey populations, and pollutant levels (Burger and Gochfeld, 2004; Monaghan, 1996; Montevecchi, 1993). Seabirds are affected by debris predominately through entanglement and ingestion, with the number of species with documented entanglements increasing from 51 species in 1997 (Laist, 1997) to 147 in 2017 (Ryan, 2018). Relatively few studies have assessed the use of debris as a nesting material by seabirds despite the potential risk of entanglement and mortality of chicks (Provencher et al., 2015; Votier et al., 2011).

Northern gannets (*Morus bassanus*) often use debris as a nesting material (Bond et al., 2012; Montevecchi, 1991), with the presence and abundance of fishing related debris in nests reflecting its the availability in the surrounding marine environment (Bond et al., 2012). The closely-related brown booby (*Sula leucogaster*) also incorporates debris within nests at a number of breeding sites (Lavers et al., 2013; Tavares et al., 2016; Verlis et al., 2014; Fig. 1A, B). Brown boobies have a pantropical distribution, occurring in the tropical Atlantic, Indian, and Pacific Oceans (Nelson, 2006), which makes them potentially ideal indicators of marine debris within this broad area, similar to northern fulmars (*Fulmarus glacialis*) which are also used as indicators of plastic ingestion in the northern hemisphere (Provencher et al., 2015; van Franeker et al., 2011). Monitoring brown booby nests has been proposed as an efficient and effective method for quantifying the magnitude of debris in the surrounding marine environment (Lavers et al., 2013; Tavares et al., 2016), although it is not clear whether the behaviour or preferences of brown booby populations are consistent among sites, as suggested by Verlis et al. (2014), who stated that brown boobies nesting in the Great Barrier Reef were not good indicators of environmental pollution.

Here we report the results of a large-scale study of brown booby

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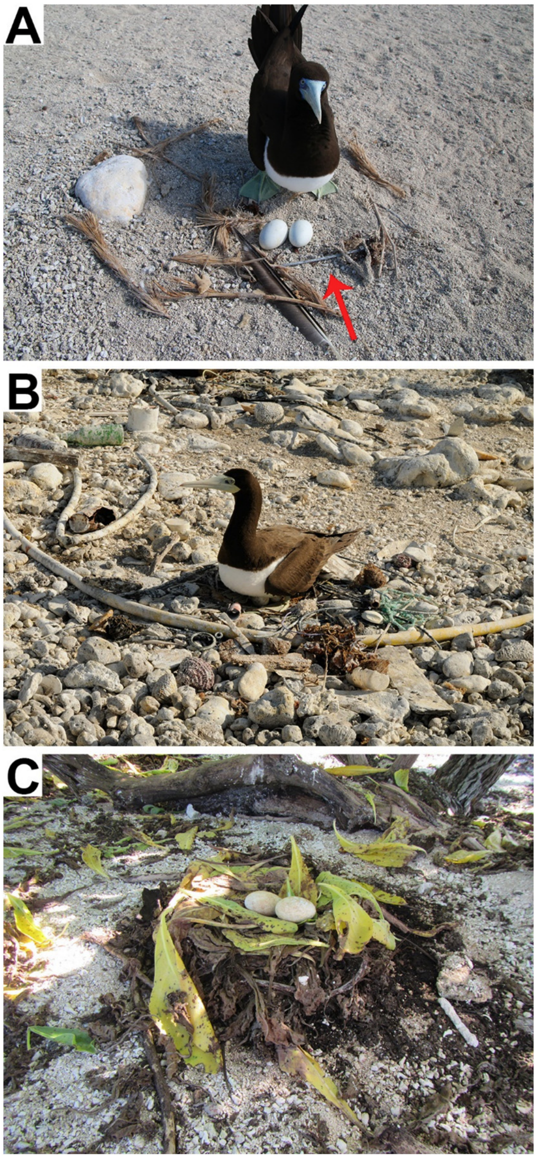

Fig. 1. The size of nests and the materials used by brown boobies varies greatly between and within sites. (A) A male brown booby on a sparse nest with one debris item (black cable tie, indicated by red arrow), Bedout Island, Timor Sea. (B) A female brown booby on a nest with a large assortment of debris items originating from a nearby shipwreck, South West Cay, Coral Sea. (C) A clean nest made entirely of *Tournefortia argentea* leaves, Rose Atoll, Pacific Ocean. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

nesting sites in order to highlight patterns in debris loads in nests and on adjacent beaches across a broad area. We assessed (1) the type, colour, number, and mass of debris items incorporated into nests of brown boobies at eighteen breeding sites across their pantropical distribution (Fig. 2), and (2) the capacity of nest debris to act as an indicator of the amount and type of debris in surrounding marine environments as reflected by the composition of debris on nesting beaches.

2. Methods

2.1. Study sites

The incidence of debris in brown booby nests and on adjacent beaches was recorded at 18 sites across their distribution between 2013 and 2018, with two of those compiled from the literature (Fig. 2, Table 1). All sites were permanent breeding islands. Three sites were surveyed multiple times over two or three years (Bedout Island twice, Porpoise Cay twice, Cato Island four times).

2.2. Nest debris surveys

All brown booby nests surveyed were > 5 m from the high tide mark and were active nests. Nests that did not contain eggs, chicks, or an adult were not included as they were considered inactive. Inactive nests may skew results due to the deterioration and loss of nest materials over time. The number of brown booby nests that did and did not contain debris was recorded. To minimise disturbance, nests were observed from a distance of approximately 5 m, and debris items were only collected if the adult bird had flushed from the nest (Lavers et al., 2013). Debris items collected from nests were labelled with the site, date, and nest number. Debris items were sorted into type and colour using standardised debris categories (Provencher et al., 2017). Type categories included sheet plastics (e.g., plastic bags), hard plastics (unidentifiable fragments from the break-up of larger plastic items, as well as intact items), threadlike plastics (rope, netting, fishing line) and foamed plastics (polystyrene) (Provencher et al., 2017). Additional categories for non-plastic debris items were also included: metal, glass and other (uncommon items such as processed timber and fabric/textiles). Colour categories were red/pink, green, blue/purple, black, grey/silver, brown/orange, yellow, and clear/white (Provencher et al., 2017). The total amount of debris from each nest was weighed to the nearest 0.1 g using an electronic balance.

2.3. Beach debris surveys

Beach transects were used to estimate the amount of debris in the surrounding marine environment at a subset of brown booby nesting sites. Depending on the size of the site and the amount of debris on the beach, one or more beach transects parallel to (and including) the high tide line was completed. In most cases, the transect dimensions were 2 × 200 m (Table 1). Data from sites with multiple transects were pooled. Data are reported as mean number of items/m^2. All surface debris > 5 mm (readily visible with no portion of items buried under sand) was collected and sorted into the categories outlined above.

2.4. Statistical analysis

All statistical analyses were completed in R 3.4.0 (R Core Team, 2017). Because some sites lacked variance (i.e., all nests had debris), generalized linear models failed to converge. We therefore used a generalized estimating equation (GEE) with a binomial error structure and logit link function in the package *geepack* v4.13-19 (Højsgaard et al., 2005) to investigate proportions of nests with and without debris at each site. Sites with repeated surveys were treated as independent as GEEs cannot accommodate repeated measures sampling, booby nests are reconstructed with each breeding attempt, and turn-over of debris items on the beach is likely to be complete from one year to the next. To further investigate any variations in proportions a Tukey post-hoc test was implemented with package *lsmeans* v2.27-2 (Lenth, 2016). The mass of debris items per nest was compared using a general linear model and the package *multcomp* v1.4-7 (Hothorn et al., 2008). The number of items per nest per site was also analysed using a general linear model with a Poisson error distribution. Pairwise comparisons were investigated for both mass and number of pieces using a Tukey post-hoc test. Results were considered significant when $p < 0.05$.

Jaccard's Index (J) of similarity was calculated using the package *vegan* v2.4-4 (Oksanen et al., 2017) to investigate similarities in the proportion of debris colours and types in booby nests across all sites, and the similarity between nest and beach debris colours and types within individual sites. The result from Jaccard's Index ranges from 0 to

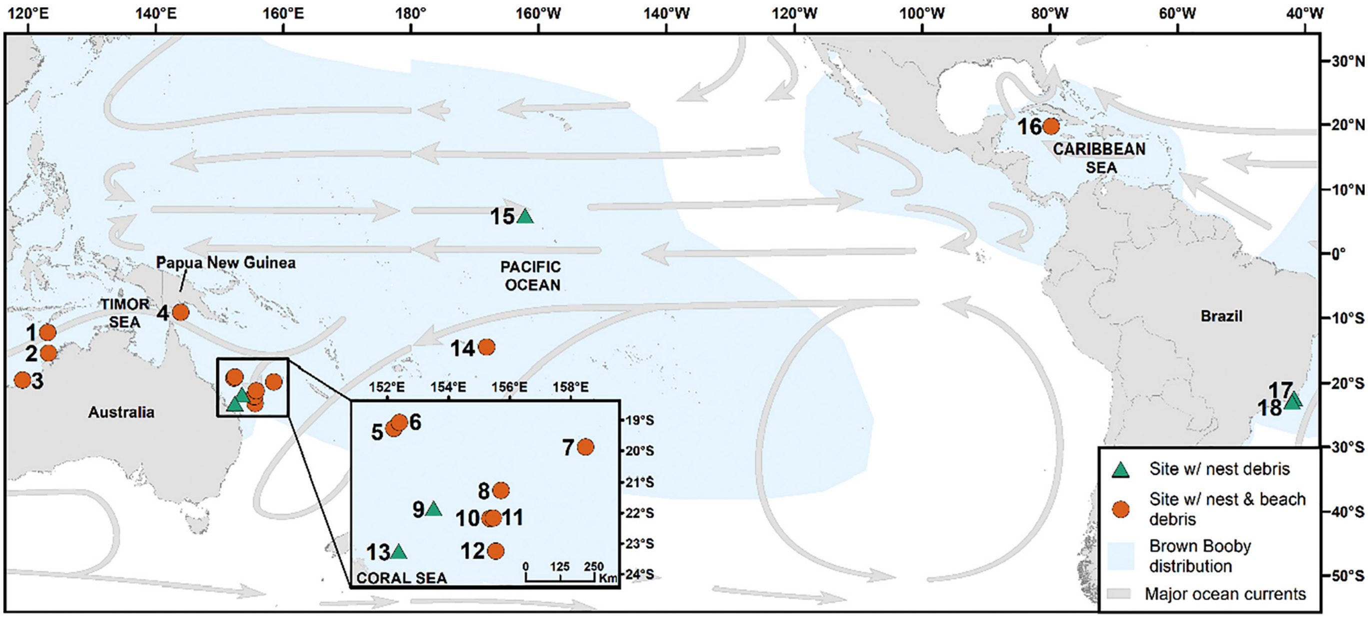

Fig. 2. Map of sampling locations (sites 1–18; Table 1) during 2013–2018. Sites where nest and beaches were surveyed are indicated by an orange circle. Sites where nests were sampled, but beaches were not, are indicated by a green triangle. The distribution of brown boobies is shown in pale blue and the grey arrows represent major ocean currents. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
Details of brown booby nest sampling locations. Sites are ordered and grouped into geographic areas (e.g. Coral Sea). The sample size reflects the total number of nests surveyed within the sampling period. The number of beach debris transects completed are reported (N/A: not applicable). Sites 3, 10, and 12 have inter-annual sampling.

No.	Site	Country	Geographic area	Coordinates	Year(s) of sampling	Sample size (n)	No. of transects	Source
1	Ashmore Reef	Australia	Timor Sea	12°20′S, 123°0′E	2013	438	1	Lavers et al. (2013)
2	Adele Island	Australia	Timor Sea	15°31′S, 123°9′E	2013	52	1	This study
3	Bedout Island	Australia	Timor Sea	19°35′S, 119°05′E	2016	232	2	This study
					2017	565	2	This study
4	Bramble Cay	Australia	Coral Sea	9°09′S, 143°52′E	2013	29	1	This study
5	Brodie Cay	Australia	Coral Sea	19°17′S, 154°13′E	2017	99	1	This study
6	Carola Cay	Australia	Coral Sea	19°5′S, 152°23′E	2017	14	2	This study
7	Ilots du Mouillage	Australia	Coral Sea	19°53′S, 158°29′E	2017	59	2	This study
8	Boulder Cay	Australia	Coral Sea	21°17′S, 155°43′E	2017	23	2	This study
9	South West Cay	Australia	Coral Sea	21°50′S, 153°30′E	2016	8	N/A	This study
10	Porpoise Cay	Australia	Coral Sea	22°12′S, 155°21′E	2017	46	2	This study
					2018	33	1	This study
11	Bird Islet	Australia	Coral Sea	22°10′S, 155°28′E	2017	31	2	This study
12	Cato Island	Australia	Coral Sea	23°15′S, 155°32′E	2016	50	2	This study
					2017a	64	2	This study
					2017b	50	N/A	This study
					2018	25	N/A	This study
13	East Fairfax	Australia	Coral Sea	23°15′S, 152°23′E	2017	50	N/A	This study
14	Rose Atoll	American Samoa	Pacific Ocean	14°32′S, 168°08′W	2017	133	2	This study
15	Palmyra Atoll	United States	Pacific Ocean	5°53′N, 162°05′W	2014	5	N/A	This study
16	Cayman Brac	Cayman Islands	Caribbean Sea	19°42′N, 79°49′W	2017	10	1	This Study
17	Santana Archipelago	Brazil	South Atlantic Ocean	22°24′S, 41°48′W	2016	118	N/A	Tavares et al. (2016)
18	Franceses Island	Brazil	South Atlantic Ocean	22°58′S, 42°02′W	2016	85	N/A	Tavares et al. (2016)

Cato Island was sampled in June 2017 (2017a) and September 2017 (2017b).

1, where $J = 0$ is a complete dissimilarity and $J = 1$ indicates a complete similarity (Real and Vargas, 1996). Results are considered significant when $J > 0.6$.

3. Results

3.1. Nest debris

A total of 2220 brown booby nests were surveyed at 18 locations over six years (2013–2018; Table 1). Of those sites, 15 (83.3%) had at least one nest which contained debris, while only two sites (11.1%) had nests containing no debris (Bird Islet, Coral Sea and Palmyra Atoll, central Pacific Ocean). Cato Island, observed four times, was found with clean nests in 2016 and June 2017. In September 2017, 24.0% of nests on Cato had debris, and in 2018, 8.0% of nests had debris. Overall the proportion of nests with and without debris at each site varied considerably, but with no discernible geographic pattern (Table 2).

Of all nests surveyed across all sites, 14.4% ($n = 319$ nests) contained debris with a mean (± SD) of 0.4 ± 2.3 items per nest (range: 0–50 items per nest; Table 2). Over half of all nests with debris contained only one item (55.4%; $n = 180$ nests; Table 2) and only a small proportion of nests contained > 10 items (5.3%; $n = 17$ nests). In total, 954 debris items from all type and colour categories were recorded. The mean mass of debris items per nest was 2.3 g ± 14.1 g

Table 2
Description of debris items present in the nests of brown boobies across sites. FO = frequency of occurrence. SD = standard deviation. N/A = Not Applicable (mass not recorded). Locations 11, 12 (years 2016 and 2017a) and 15 contained only clean nests. Locations that share the same superscript have proportions of nests with and without debris that are not significantly different from each other, have mean masses (g) that are not significantly different from each other, or the mean number of items are not significantly different from each other ($p < 0.05$).

Location	Sample size (n)	FO (%)	Mass (g)		Items per nest		Total items
			Mean ± SD	Range	Mean ± SD	Range	
1. Ashmore	438	11.2^{d}	0.9 ± 5.1^{b}	0.0–52.0	0.1 ± 0.3^{bc}	0.0–2.0	50
2. Adele	52	3.8^{abcd}	0.2 ± 1.2^{bc}	0.0–8.7	0.0 ± 0.2^{abcd}	0.0–1.0	2
3. Bedout							
2016	232	5.6^{bcd}	1.0 ± 8.3^{b}	0.0–112.4	0.1 ± 0.3^{abc}	0.0–2.0	15
2017	565	2.7^{bc}	0.4 ± 5.2^{b}	0.0–110.4	0.0 ± 0.2^{a}	0.0–1.0	15
4. Bramble	29	82.8^{efg}	N/A	N/A	1.2 ± 0.9^{efg}	0.0–4.0	36
5. Brodie	99	11.1^{abcd}	4.5 ± 27.1^{ab}	0.0–233.3	0.1 ± 0.4^{bc}	0.0–2.0	13
6. Carola	14	42.9^{abcdef}	26.9 ± 52.7^{d}	0.0–185.0	1.3 ± 1.7^{efg}	0.0–5.0	18
7. Mouillage	59	15.3^{abcd}	2.6 ± 10.4^{ab}	0.0–64.4	0.2 ± 0.6^{cd}	0.0–3.0	14
8. Boulder	23	91.3^{fg}	55.1 ± 52.4^{e}	0.0–184.0	3.9 ± 4.2^{h}	0.0–19.0	89
9. South West	8	100.0^{g}	N/A	N/A	29.9 ± 10.6^{j}	15.0–50.0	239
10. Porpoise							
2017	46	2.2^{abcd}	0.8 ± 5.1^{bc}	0.0–34.8	0.0 ± 0.1^{abcd}	0.0–1.0	1
2018	33	12.1^{abcd}	1.0 ± 5.2^{ab}	0.0–29.9	0.1 ± 0.3^{abcd}	0.0–1.0	4
11. Bird	31	0.0^{a}					
12. Cato							
2016	50	0.0^{a}					
2017a	64	0.0^{a}					
2017b	50	24.0^{cd}	8.1 ± 24.7^{ac}	0.0–121.1	0.5 ± 1.4^{de}	0.0–8.0	27
2018	25	8.0^{abcd}	N/A	N/A	0.1 ± 0.3^{abcd}	0.0–1.0	2
13. Fairfax	50	12.0^{abcd}	3.2 ± 9.5^{ab}	0.0–39.3	0.2 ± 0.5^{bcd}	0.0–3.0	8
14. Rose	133	1.5^{ab}	0.3 ± 2.9^{b}	0.0–32.6	0.0 ± 0.1^{ab}	0.0–1.0	2
15. Palmyra	5	0.0^{a}					
16. Cayman	10	100.0^{g}	32.4 ± 15.8^{d}	9.1–55.0	7.6 ± 2.7^{i}	4.0–11.0	76
17. Santana	119	62.2^{e}	8.9 ± 30.6^{a}	0.0–284.7	2.0 ± 3.0^{g}	0.0–19.0	240
18. Franceses	85	58.8^{e}	2.4 ± 5.7^{bc}	0.0–42.8	1.2 ± 1.5^{f}	0.0–8.0	103
Overall	2220	14.4	2.3 ± 14.1	0.0–284.7	0.4 ± 2.3	0.0–50.0	954

(range = 0.0–284.7 g; Table 2) and differed significantly among sites ($F_{21,\ 2133} = 21.4$; $p < 0.001$). Santana Archipelago had the greatest mass of debris items in a single nest at 284.7 g, while nests on Boulder Cay had the highest mean mass per nest (55.1 ± 52.4 g; range: 0.0–184.0 g).

Overall, plastics (hard, threadlike, foamed and sheet; 90.1%; $n = 860$ items) were more abundant than all other non-plastic debris types (metal, glass, other; 9.9%; $n = 94$ items; Fig. 3). Of those plastic categories, hard plastics were consistently the most frequent type of debris found within nests across all sites and accounted for half of all debris items (50.6%; $n = 483$ items). Many sites had similar compositions of debris types ($n = 29$ similarities when $J > 0.6$; Table S1). The highest degree of similarity was between nests on Cayman Brac and Ilots du Mouillage ($J = 0.85$).

White/clear debris was the most common colour across all sites (27.3%; $n = 260$ items; Fig. 4), followed by black (22.7%; $n = 217$ items). Interestingly, green was the most abundant colour at Ashmore Reef (24.0%; $n = 12$ items) despite it being one of the least common colours overall (6.5%; $n = 62$ items). Fewer similarities were found in colour compositions between sites ($n = 14$ similarities when $J > 0.6$; Table S2). The colours of items in nests on Cayman Brac and Franceses Island displayed the highest degree of similarity ($J = 0.76$).

3.2. Beach debris

A total of 26 beach transects were undertaken across 13 sites over six years (Table 1). Of those sites, 84.6% ($n = 11$ sites) had transects with debris present, while 15.4% ($n = 2$ sites; Brodie Cay and Carola Cay) did not have any debris (Table 3). Cayman Brac had the greatest density of debris and the greatest number of debris items overall (5.833 items m^{-2}; $n = 70$ items). In total, 333 items were recorded in beach transects from all colour and type categories. Hard plastic was the most frequent debris type observed in beach transects (68.2%; $n = 227$ items) and was consistently the most common type at all locations with beach transects. The colour of debris items recovered from beach transects was less consistent. White/clear items accounted for 42.9% ($n = 143$ items), followed by blue/purple (20.1%; $n = 67$ items) and black (12.0%; $n = 40$ items).

3.3. Comparative analysis between nest and beach debris within sites

Comparisons between nest debris and beach debris types and colours within sites were possible for ten of the 18 sites (Brodie Cay, Carola Cay, South West Cay, Cato Island, East Fairfax, Palmyra Atoll, Santana Archipelago, and Franceses Island were excluded because nests or beaches had no debris, or because no transects were completed). The highest degree of similarity in the proportion of debris types was found at Ashmore Reef ($J = 0.71$), followed by Cayman Brac ($J = 0.68$), Boulder Cay ($J = 0.67$; Table S1). Similarities in the proportions of colours was less common, with Bedout Island in 2016 having the only significant result ($J = 0.66$; Table S2).

4. Discussion

Ocean currents are integral to the movement and dispersal of marine debris around the world (Maes and Blanke, 2015). Debris densities on beaches can increase by up to 40% during periods of high use from improper disposal by beachgoers (Galgani et al., 2015). However, as brown boobies generally nest on uninhabited islands located far from metropolitan and populated centres (Nelson, 1978), the accumulation of debris on nesting beaches is generally classified as flotsam, transported by currents and originating from land- and marine-based sources further afield. Bramble Cay and Ashmore Reef are located within the Indonesian Throughflow, yet the proportion of nests with debris is vastly different. On Ashmore, only 11.2% of nests contained debris while 82.8% of nests on Bramble had debris (Table 2). This may

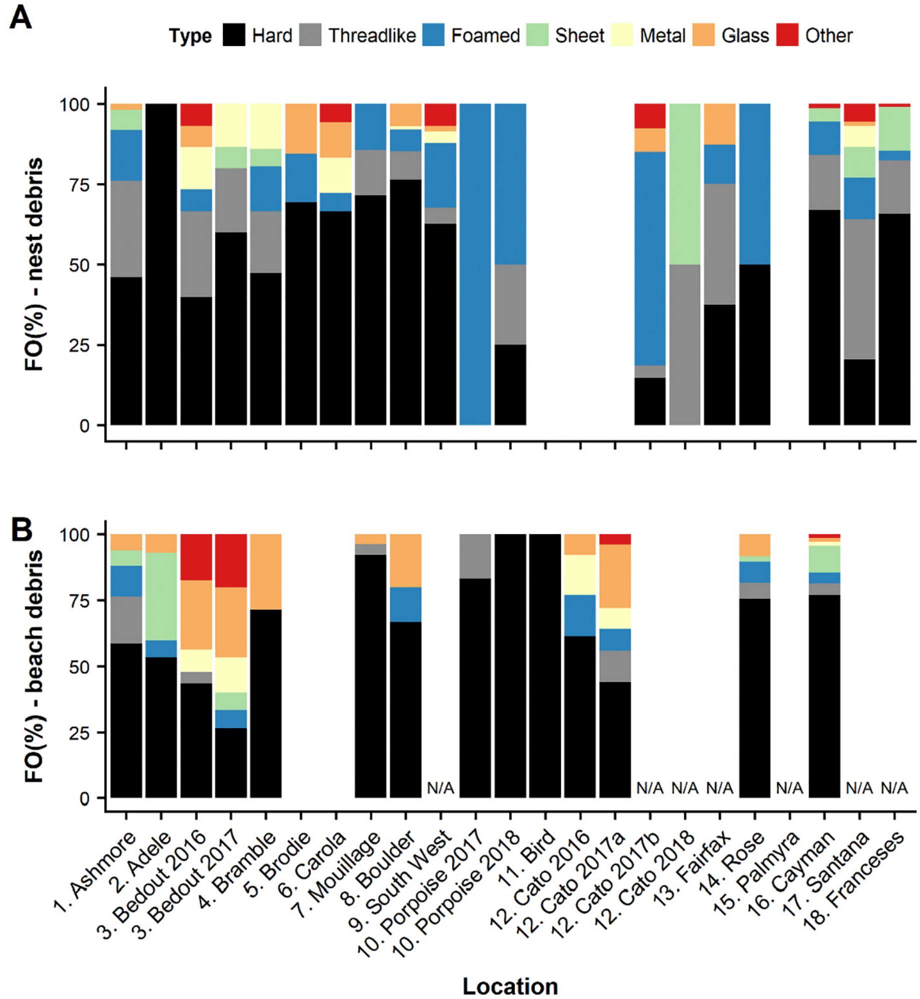

Fig. 3. Frequency of occurrence (FO; %) of debris types in A) brown booby nests and B) beach debris transects at a sub-set of beaches adjacent to brown booby nesting sites. Sample sizes for each site are reported in Table 2. N/A = Not Applicable (no debris transect completed). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

be due to the proximity of Bramble to the mouth of the Fly River, the largest river in Papua New Guinea by flow volume (Ferguson et al., 2011). Combined with PNG's limited waste management capacity (Smith, 2012), the Fly River may influence the amount of debris entering the ocean and subsequently washing up on Bramble Cay (Lebreton et al., 2017).

Brown boobies nesting on coastal islands were more likely to use debris as a nest material due to the prevalence of it in comparison to other (more remote) sites. Santana Archipelago and Franceses Island are located < 5 km from the coast of Rio de Janeiro State, Brazil. Both sites exhibited high proportions of nests with debris (62.2% and 58.8% respectively; Table 2), with 36.2% of all debris items recovered during this study found within the nests of these two islands. Cayman Brac, unique in that it is the only study site inhabited by humans, had extremely high debris loads. This may be attributed to waste management practices and the influence of tourism and local populations which are common factors that contribute to high debris loads on Caribbean beaches (Coe et al., 1997; Ivar do Sul and Costa, 2007; Schmuck et al., 2017). All nests (n = 10) contained debris with a mean of 7.6 ± 2.7 items (though the sample size was small relative to other sites), while the beach had the highest density of debris of all sites (5.833 items m^{-2}; Table 3).

In comparison, brown booby nests on Palmyra Atoll in the central Pacific Ocean (> 1700 km from the closest metropolitan centre) were completely free from debris. However, remoteness and distance from populated areas and human activities does not necessarily confer safety and protection from debris. Brown booby breeding sites examined by Verlis et al. (2014) in the Coral Sea – a large, relatively remote area – displayed high levels of debris in nests, with a mean of 4.1 ± 4.7 items per nest and mean mass of 6.2 ± 10.9 g. This is relatively consistent with findings from this study. Ten sites were studied in the Coral Sea with a mean of 0.8 ± 3.9 items per nest and mean mass of 4.6 ± 21.6 g. Slight differences may be due to differences in sampling years and/or the dynamic nature of ocean systems. Proximity to oceanographic features, such as currents, as well metropolitan centres, may not always explain observed patterns as other variables, such as activities at sea, can influence debris loads (Law, 2017).

Commercial and recreational fishing is undertaken all around the world with the loss and abandonment of fishing gear accounting for approximately 18% of the total ocean debris load (Andrady, 2011). In the majority of sites studied, hard plastic fragments dominated the debris load. However, on Santana Archipelago, threadlike plastics (rope, monofilament line, netting) were the most abundant (43.8%; Fig. 3). This is related to the large number of trawl vessels operating in the surrounding waters (Tavares et al., 2016). This pattern was also observed for northern gannets in Newfoundland, where gillnet fisheries operated and consequently, high abundances of fishing gear were found in the nests (Bond et al., 2012).

Another source of debris that is not commonly discussed is shipwrecks. When exposed to harsh conditions, such as exposed beaches,

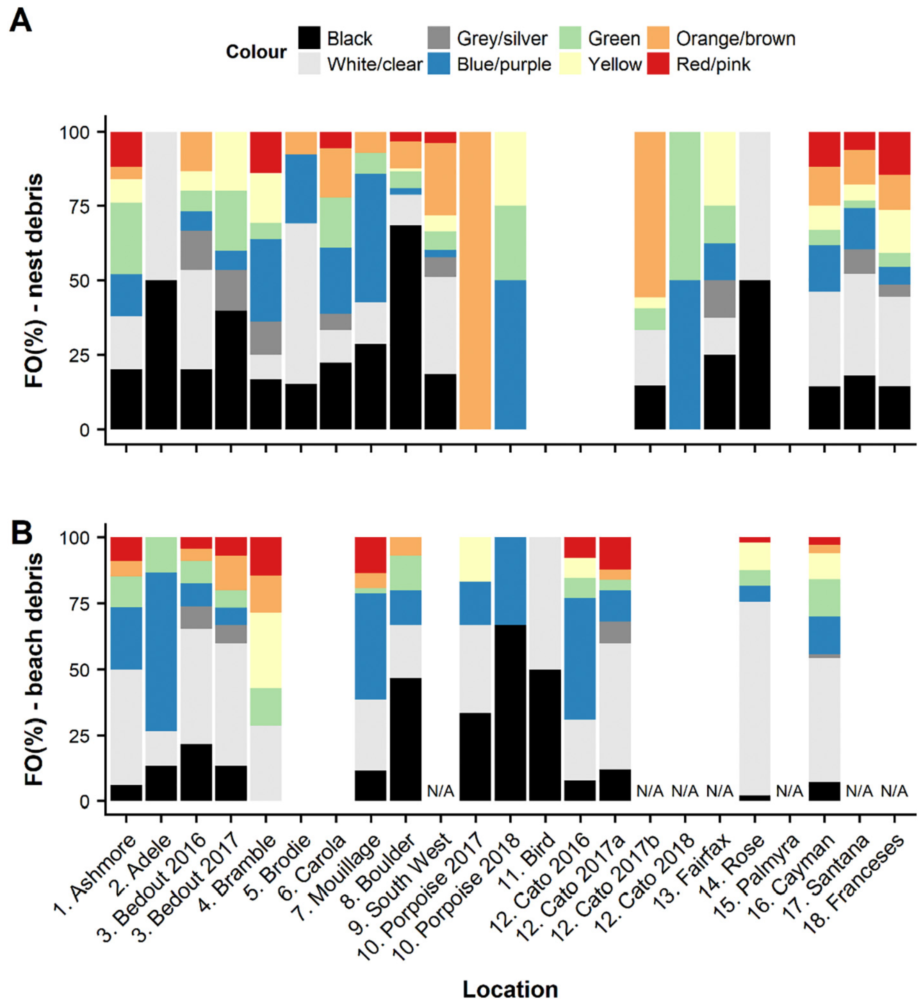

Fig. 4. Frequency of occurrence (FO; %) of debris colours in A) brown booby nests and B) beach debris transects at a sub-set of beaches adjacent to brown booby nesting sites. Sample sizes for each site are reported in Table 2. N/A = Not Applicable (no debris transect completed). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

shipwrecks have the potential to disintegrate quickly and generate more debris than sunken vessels (Katsanevakis, 2008; Masetti and Calder, 2014). The abundance of debris items in brown booby nests at Boulder Cay and South West Cay (3.9 ± 4.2 items and 29.9 ± 10.6 items respectively; Fig. 1b, Table 2) were heavily influenced by the presence of shipwrecks. While these nests contained debris items originating from other sources, the majority of items came directly from the wrecks. We suggest that these nests may be an indication of what nests will look like in coming years as the mass of plastic and other waste in oceans worldwide is estimated to increase (Jambeck et al., 2015), and highlights the urgency with which equitable global solutions to plastic waste are needed (Borrelle et al., 2017).

A wide range of factors influence the types and colours of nest materials chosen by birds (e.g. Bennett et al., 1994). Male brown boobies are the main collectors of nest debris, but it is the female's decision whether the material will be incorporated within the nest (Marchant and Higgins, 1990). Male brown boobies may therefore be purposefully collecting – and presenting – debris items based on their colour and what they believe will impress their mate. Alternatively, brown boobies may also select debris that resembles natural materials (Lavers et al., 2013). Boobies use a variety of materials in nest construction, including vegetation, coral, and bones, and therefore, may be selecting debris items based on their colour (i.e., within the natural colour spectrum – black, white/clear, orange/brown, green) or their shape (e.g. elongated). Although proximity to vegetation was not considered during this study, there appears to be some notable differences. On Rose Atoll where only two nests contained debris (FO = 1.5%; Fig. 1C) there was an abundance of natural nesting material available. Similarly, on Cato Island no nests were recorded to contain debris in June 2016 or June 2017, when natural vegetation was readily available. However, in September 2017, natural vegetation was sparse (Stuckenbrock pers. obs.), and 24.0% of nests were observed to contain debris. This contradicts Verlis et al. (2014) suggestion that it's unlikely the presence of natural vegetation on breeding islands in the Coral Sea region would reduce the use of debris as a nest material. Both Cato Island and Rose Atoll had plastic items recorded during beach transects, which may suggest that while debris is available to use as a nest material, boobies prefer to use natural vegetation when abundant in the nesting area.

While gannets are known to collect nest material from the marine environment, there is limited information on where and how far brown boobies will travel to collect nest materials. Studies on red-footed boobies (*Sula sula*) suggest they gather material from the immediate area around the nest and are opportunistic, often stealing from unattended conspecifics' nests (Verner, 1961). This behaviour is notorious in Pelicaniformes, and has been observed in gannets as well as masked boobies (*Sula dactylatra*; Marchant and Higgins, 1990). Brown boobies are also thought to collect nest materials primarily from the area surrounding their nest (Lavers pers. obs.) and have been observed to steal from conspecifics' nests (Grant pers. obs.), but collection from the sea

Table 3
Description of debris items recorded during beach debris transects completed at a sub-set of beaches adjacent to brown booby breeding sites. N/A = Not Applicable (no debris transect completed). The total number of transects are reported in Table 1.

Location	Area surveyed (m^2)	Debris present	Total items	Items/m^2
1. Ashmore	400	Yes	34	0.085
2. Adele	400	Yes	15	0.038
3. Bedout				
2016	4750	Yes	23	0.005
2017	3750	Yes	15	0.004
4. Bramble	2500	Yes	7	0.003
5. Brodie	400	No	0	0.000
6. Carola	200	No	0	0.000
7. Mouillage	300	Yes	52	0.173
8. Boulder	200	Yes	15	0.075
9. South West	N/A			
10. Porpoise	800	Yes	6	0.008
2017	800	Yes	6	0.008
2018	1000	Yes	5	0.005
11. Bird	800	Yes	4	0.005
12. Cato				
2016	120	Yes	13	0.108
2017a	800	Yes	25	0.031
2017b	N/A			
2018	N/A			
13. Fairfax	N/A			
14. Rose	800	Yes	49	0.061
15. Palmyra	N/A			
16. Cayman	12	Yes	70	5.833
17. Santana	N/A			
18. Franceses	N/A			

cannot be ruled out within ~50 km of the colony, as reflected by typical foraging movements (Soanes et al., 2015). The evidence presented here suggests brown boobies may be reliable sentinels for certain types or colours of beach-washed debris, specific to their breeding location.

The variety of colours and types of items in the nests of brown boobies is highly dynamic across their distribution, reflecting similar observations from the marine environment. The majority of brown boobies were selecting debris items based on colour and type, with J values typically < 0.6, indicating active selection by most birds. Interestingly, there is minimal evidence that selection for colour or type is consistent across populations. Out of 171 comparisons among debris colour in nests among sites, only 14 (8.2%) exhibited $J > 0.6$ (Table S2), suggesting selection behaviour is occurring at the local level. This indicates observations made using single populations do not accurately capture variation in population-specific behaviour, meaning trends at one site may not reflect patterns across the broader ecosystem.

Entanglement in, and ingestion of debris poses a significant threat to many marine species (Gall and Thompson, 2015), with interactions between debris and seabirds most likely to occur at sea where they forage for food. Yet for seabird species that use debris as a nest material, entanglement and ingestion may occur within the nest or at the breeding site (Votier et al., 2011). There is, however, little evidence of either event occurring in tropical sulids, and as such, the risk is thought to be very low. There is one record of a brown booby ingesting debris on the Hawaiian islands (Rapp et al., 2017), and one record of entanglement on Ashmore Reef (Lavers et al., 2013). However, chicks have been observed playing with nest materials which could increase the chance of entanglement (Nelson, 1978; Bodden-Harris pers. comm.) and debris items that form loops or are long (such as threadlike plastics; 20.0% of nest debris items) pose more of a hazard (Gregory, 2009). The low frequency of entanglement and ingestion currently observed in brown boobies is unlikely to contribute to population-level consequences. However, it is important to consider the potential hazards as debris loads in the marine environment are predicted to increase in coming years (PlasticsEurope, 2017; World Economic Forum, 2016).

5. Conclusion

When debris is available, brown boobies will use it within their nests, and this pattern is consistent across their pantropical distribution. The level of debris in marine environments is set to increase in line with human population growth (Jambeck et al., 2015) and we expect that the frequency of brown booby nests with debris and the quantity of items within each nest will increase as well.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpolbul.2018.10.016.

References

Andrady, A.L., 2011. Microplastics in the marine environment. Mar. Pollut. Bull. 62, 1596–1605.
Barnes, D.K.A., Galgani, F., Thompson, R.C., Barlaz, M., 2009. Accumulation and fragmentation of plastic debris in global environments. Philos. Trans. R. Soc. B 364, 1985–1998.
Bennett, A.T.D., Cuthill, I.C., Norris, K.J., 1994. Sexual selection and the mismeasure of colour. Am. Nat. 144, 848–860.
Bond, A.L., Montevecchi, W.A., Guse, N., Regular, P.M., Garthe, S., Rail, J.F., 2012. Prevalence and composition of fishing gear debris in the nests of northern gannets (*Morus bassanus*) are related to fishing effort. Mar. Pollut. Bull. 64, 907–911.
Borrelle, S.B., Rochman, C.M., Liboiron, M., Bond, A.L., Lusher, A., Bradshaw, H., Provencher, J.F., 2017. Opinion: why we need an international agreement on marine plastic pollution. Proc. Natl. Acad. Sci. U. S. A. 114, 9994–9997.
Burger, J., Gochfeld, M., 2004. Marine birds as sentinels of environmental pollution. EcoHealth 1, 263–274.
Cairns, D.K., 1987. Seabirds as indicators of marine food supplies. Biol. Oceanogr. 5, 261–271.
Coe, J.M., Andersson, S., Rogers, D.B., 1997. Marine debris in the Caribbean region. In: Coe, J.M., Rogers, D.B. (Eds.), Marine Debris: Sources, Impacts, and Solutions. Springer, New York, NY, pp. 25–33.
Dale, V.H., Beyeler, S.C., 2001. Challenges in the development and use of ecological indicators. Ecol. Indic. 3–10.
van der Velde, T., Milton, D.A., Lawson, T.J., Wilcox, C., Lansdell, M., Davis, G., Perkins, G., Hardesty, B.D., 2017. Comparison of marine debris data collected by researchers and citizen scientists: is citizen science data worth the effort? Biol. Conserv. 208, 127–138.
Eriksen, M., Lebreton, L.C.M., Carson, H.S., Thiel, M., Moore, C.J., Borerro, J.C., Galgani, F., Ryan, P.G., Reisser, J., 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.
Ferguson, P.R., Dubois, K.D., Viezer, J., 2011. Fluvial carbon fluxes under extreme rainfall conditions: inferences from the Fly River, Papua New Guinea. Chem. Geol. 281, 283–292.
van Franeker, J.A., Blaize, C., Danielsen, J., Fairclough, K., Gollan, J., Guse, N., Hansen, P.L., Heubeck, M., Jensen, J.K., Le Guillou, G., Olsen, B., Olsen, K.O., Pedersen, J., Stienen, E.W., Turner, D.M., 2011. Monitoring plastic ingestion by the northern fulmar *Fulmarus glacialis* in the North Sea. Environ. Pollut. 159, 2609–2615.
Galgani, F., Hanke, G., Maes, T., 2015. Global distribution, composition and abundance of marine litter. In: Bergmann, M., Gutow, L., Klages, M. (Eds.), Marine Anthropogenic Litter. Springer International Publishing, pp. 29–56.
Gall, S.C., Thompson, R.C., 2015. The impact of debris on marine life. Mar. Pollut. Bull. 92, 170–179.
Gregory, M.R., 2009. Environmental implications of plastic debris in marine settings-

entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. Philos. Trans. R. Soc. Lond. Ser. B Biol. Sci. 364, 2013–2025.
Højsgaard, S., Halekoh, U., Yan, J., 2005. The R package geepack for generalized estimating equations. J. Stat. Softw. 15, 1–11.
Hothorn, T., Bretz, F., Westfall, P., 2008. Simultaneous inference in general parametric models. Biom. J. 50, 346–363.
Ivar do Sul, J.A., Costa, M.F., 2007. Marine debris review for Latin America and the Wider Caribbean Region: from the 1970s until now, and where do we go from here? Mar. Pollut. Bull. 54, 1087–1104.
Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., Law, K.L., 2015. Plastic waste inputs from land into the ocean. Science 347, 768–771.
Katsanevakis, S., 2008. Marine debris, a growing problem: sources, distribution, composition, and impacts. In: Hofer, T.N. (Ed.), Marine Pollution: New Research. Nova Science Publishers, New York, pp. 53–100.
Laist, D.W., 1997. Impacts of marine debris: entanglement of marine life in marine debris including a comprehensive list of species with entanglement and ingestion records. In: Coe, J.M., Rogers, D.B. (Eds.), Marine Debris: Sources, Impacts, and Solutions. Springer-Verlag, New York, pp. 99–139.
Lavers, J.L., Bond, A.L., 2017. Exceptional and rapid accumulation of anthropogenic debris on one of the world's most remote and pristine islands. Proc. Natl. Acad. Sci. U. S. A. 114, 6052–6055.
Lavers, J.L., Hodgson, J.C., Clarke, R.H., 2013. Prevalence and composition of marine debris in Brown Booby (*Sula leucogaster*) nests at Ashmore Reef. Mar. Pollut. Bull. 77, 320–324.
Law, K.L., 2017. Plastics in the marine environment. Annu. Rev. Mar. Sci. 9, 205–229.
Lebreton, L.C.M., van der Zwet, J., Damsteeg, J.-W., Slat, B., Andrady, A., Reisser, J., 2017. River plastic emissions to the world's oceans. Nat. Commun. 8, 15611.
Lenth, R.V., 2016. Least-squares means: the R package lsmeans. J. Stat. Softw. 69, 1–33.
Lippiatt, S., Opfer, S., Arthur, C., 2013. Marine Debris Monitoring and Assessment, NOAA Technical Memorandum NOS-OR&R-46.
Maes, C., Blanke, B., 2015. Tracking the origins of plastic debris across the Coral Sea: a case study from the Ouvea Island, New Caledonia. Mar. Pollut. Bull. 97, 160–168.
Marchant, S., Higgins, P.J., 1990. Handbook of Australian, New Zealand and Antarctic Birds. Oxford University Press.
Masetti, G., Calder, B., 2014. Design of a standardized geo-database for risk monitoring of potentially polluting marine sites. Environ. Syst. Decis. 34, 138–149.
Monaghan, P., 1996. Relevance of the behaviour of seabirds to the conservation of marine environments. Oikos 77, 227–237.
Montevecchi, W.A., 1991. Incidence and types of plastic in gannets' nests in the Northwest Atlantic. Can. J. Zool. 69, 295–297.
Montevecchi, W.A., 1993. Birds as indicators of change in marine prey stocks. In: Furness, R.W., Greenwood, D.J. (Eds.), Birds as Monitors of Environmental Change. Chapman & Hall, London, pp. 261–271.
Nelson, J.B., 1978. Brown booby. In: Nelson, J.B. (Ed.), The Sulidae. Gannets and Boobies. Oxford University Press, pp. 417–505.
Nelson, J.B., 2006. Pelicans, Cormorants, and Their Relatives: Pelecanidae, Sulidae, Phalacrocoracidae, Anhingidae, Fregatidae, Phaethontidae. Oxford University Press, Oxford.
Oksanen, J., Blanchet, F.G., Friendly, M., Kindt, R., Legendre, P., McGilinn, D., Minchin, P.R., O'Hara, R.B., Simpson, G.L., Solymos, P., Stevens, M.H.M., Szoecs, E., Wagner, H., 2017. Vegan: Community Ecology Package. R Package Version 2.4-4.
Piatt, J.F., Sydeman, W.J., Wiese, F., 2007. Introduction: seabirds as indicators of marine ecosystems. Mar. Ecol. Prog. Ser. 352, 199–204.
PlasticsEurope, 2017. Plastics - The Facts 2017: An Analysis of European Plastics Production, Demand and Waste Data. PlasticsEurope, Brussels, Belgium.
Provencher, J.F., Bond, A.L., Mallory, M.L., 2015. Marine birds and plastic debris in Canada: a national synthesis and a way forward. Environ. Rev. 23, 1–13.
Provencher, J.F., Bond, A.L., Avery-Gomm, S., Borrelle, S.B., Bravo Rebolledo, E.L., Hammer, S., Kuhn, S., Lavers, J.L., Mallory, M.L., Trevail, A., van Franeker, J.A., 2017. Quantifying ingested debris in marine megafauna: a review and recommendations for standardization. Anal. Methods 9, 1454–1469.
R Core Team, 2017. R: A Language and Environment for Statistical Computing, Version 3.4.0 [Computer Program]. R Foundation for Statistical Computing, Vienna, Austria.
Rapp, D.C., Youngren, S.M., Hartzell, P., Hyrenbach, D.K., 2017. Community-wide patterns of plastic ingestion in seabirds breeding at French Frigate Shoals, northwestern Hawaiian Islands. Mar. Pollut. Bull. 123, 269–278.
Real, R., Vargas, J.M., 1996. The probabilistic basis of Jaccard's Index of Similarity. Syst. Biol. 45, 380–385.
Ryan, P.G., 2018. Entanglement of birds in plastics and other synthetic materials. Mar. Pollut. Bull. 135, 159–164.
Schmuck, A.M., Lavers, J.L., Stuckenbrock, S., Sharp, P.B., Bond, A.L., 2017. Geophysical features influence the accumulation of beach debris on Caribbean islands. Mar. Pollut. Bull. 121, 45–51.
Smith, S.D., 2012. Marine debris: a proximate threat to marine sustainability in Bootless Bay, Papua New Guinea. Mar. Pollut. Bull. 64, 1880–1883.
Soanes, L.M., Bright, J.A., Bolton, M., Millett, J., Mukhida, F., Green, J.A., 2015. Foraging behaviour of Brown boobies *Sula leucogaster* in Anguilla, Lesser Antilles: preliminary identification of at-sea distribution using a time-in-area approach. Bird Conserv. Int. 25, 87–96.
Tavares, D.C., da Costa, L.L., Rangel, D.F., de Moura, J.F., Zalmon, I.R., Siciliano, S., 2016. Nests of the brown booby (*Sula leucogaster*) as a potential indicator of tropical ocean pollution by marine debris. Ecol. Indic. 70, 10–14.
Verlis, K.M., Campbell, M.L., Wilson, S.P., 2014. Marine debris is selected as nesting material by the brown booby (*Sula leucogaster*) within the Swain Reefs, Great Barrier Reef, Australia. Mar. Pollut. Bull. 87, 180–190.
Verner, J., 1961. Nesting activities of the Red-Footed Booby in British Honduras. Auk 78, 573–594.
Votier, S.C., 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.
World Economic Forum, 2016. The New Plastics Economy - Rethinking the Future of Plastics. Ellen MacArthur Foundation and Mckinsey & Company.
Zettler, E.R., Takada, H., Monteleone, B., Mallos, N., Eriksen, M., Amaral-Zettler, L.A., 2017. Incorporating citizen science to study plastics in the environment. Anal. Methods 9, 1392–1403.

Supplementary Material

Table S1

Values (J) of Jaccard's Index for comparing debris type between sites and between nest (N) and beach (B) debris at Brown Booby breeding locations. J values are considered significant when $J > 0.6$. UNDERLINED values represent a high degree of overlap between nest and beach debris types per site, thus indicating *no active selection* by the birds. Values in **BOLD** represent significant similarities between nest debris types across sites. Values in WAVY UNDERLINE represent similarities in debris types at beaches. Irrelevant J values have been removed for improved readability (comparisons between nest debris types and beach debris types at different sites). Sites 5. B, 6. B, 11. N, 12. N^{16}, 12. N^{17a} and 15. N are not included in this table as they were clean. The superscript on sites 3, 10 and 12 refer to the sampling year.

SITE	1. N	1. B	2. N	2. B	3. N^{16}	3. B^{16}	3. N^{17}	3. B^{17}	4. N	4. B	5. N	6. N	7. N	7. B	8. N	8. B	9. N	10. N^{17}	10. B^{17}	10. N^{18}	10. B^{18}	11. B	12. B^{16}	12. B^{17a}	12. N^{17b}	12. N^{18}	13. N	14. N	14. B	16. N	16. B	17. N
1. B	0.71																															
2. N	0.30																															
2. B		0.56	0.36																													
3. N^{16}	**0.60**		0.25																													
3. B^{16}		0.37		0.33	0.50																											
3. N^{17}	0.56		0.43		0.58	0.39																										
3. B^{17}		0.29		0.30	0.43	0.65	0.30																									
4. N	**0.74**		0.31		**0.66**		**0.75**																									
4. B		0.48		0.43		0.53		0.36	0.31																							
5. N	0.46		0.53		0.36		0.43		0.44																							
6. N	0.37		0.50		0.53		0.55		0.47		**0.71**																					
7. N	0.59		0.56		0.44		0.59		**0.61**		**0.72**	0.57																				
7. B		0.50		0.40		0.34		0.18		0.60			0.60																			
8. N	0.47		**0.62**		0.46		0.54		0.47		**0.71**	**0.67**	**0.77**																			
8. B		0.62		0.50		0.46		0.36		0.76				0.54	0.67																	
9. N	0.52		0.46		0.47		0.52		0.54		**0.66**	**0.66**	**0.70**		**0.63**																	
10. N^{17}	0.09		0.00		0.03		0.00		0.07		0.08	0.03	0.08		0.03		0.11															
10. B^{17}		0.61		0.36		0.31		0.15		0.56				0.77		0.50		0.00														
10. N^{18}	0.49		0.14		0.40		0.29		0.41		0.25	0.18	0.37		0.26		0.33	0.33	0.26													
10. B^{18}		0.55		0.43		0.28		0.20		0.43				0.43		0.58		0.25	0.43	0.48												
11. B		0.42		0.36		0.28		0.15		0.56				0.86		0.50			0.71		0.43											
12. B^{16}		0.62		0.50		0.43		0.37		0.53				0.49		0.70			0.44		0.60	0.44										
12. B^{17a}		0.54		0.40		0.72		0.53		0.52				0.35		0.56			0.39		0.35	0.28	0.51									
12. N^{17b}	0.22		0.08		0.24		0.10		0.19		0.23	0.20	0.20		0.19		0.31	0.50		0.52			0.23	0.23								
12. N^{18}	0.22		0.00		0.15		0.15		0.14		0.00	0.00	0.08		0.05		0.03	0.00		0.14			0.06	0.06	0.02							
13. N	**0.69**		0.23		**0.63**		0.40		0.53		0.45	0.37	0.47		0.43		0.40	0.07		0.45					0.24	0.23						
14. N	0.45		0.33		0.30		0.33		0.44		0.49	0.38	0.47		0.40		0.54	0.33		**0.60**					0.48	0.00	0.33					
14. B		0.68		0.52		0.39		0.28		0.66				0.71		0.71			0.69		0.52	0.61	0.50	0.50				0.41				
16. N	**0.63**		0.51		0.48		**0.68**		**0.65**		**0.63**	0.58	**0.85**		**0.71**		**0.66**	0.06		0.36					0.18	0.12	0.48	0.43				
16. B		0.60		0.53		0.35		0.27		0.57				0.70		0.57			0.69		0.47	0.63	0.40	0.40					0.78	0.68		
17. N	0.55		0.11		0.50		0.37		0.48		0.21	0.24	0.31		0.24		0.32	0.07		0.41					0.24	0.36	0.56	0.20		0.36		
18. N	0.56		0.49		0.43		**0.71**		0.56		0.53	0.54	**0.71**		**0.64**		0.56	0.01		0.29					0.13	0.18	0.40	0.36		**0.82**		0.34

Table S2

Values (J) of Jaccard's Index for comparing debris colour between sites and between nest (N) and beach (B) debris at Brown Booby breeding locations. J values are considered significant when $J > 0.6$. UNDERLINED values represent a high degree of overlap between nest and beach debris colours per site, thus indicating *no active selection* by the birds. Values in **BOLD** represent significant similarities between nest debris colours across sites. Values in WAVY UNDERLINE represent similarities in debris colours at beaches. Irrelevant J values have been removed for improved readability (comparisons between nest debris colours and beach debris colour at different sites). Sites 5. B, 6. B, 11. N, 12. N^{16}, 12. N^{17a} and 15. N are not included in this table as they were clean. The superscript on sites 3, 10 and 12 refer to the sampling year.

SITE	1. N	1. B	2. N	2. B	3. N^{16}	3. B^{16}	3. N^{17}	3. B^{17}	4. N	4. B	5. N	6. N	7. N	7. B	8. N	8. B	9. N	10. N^{17}	10. B^{17}	10. N^{18}	10. B^{18}	11. B	12. B^{16}	12. B^{17a}	12. N^{17b}	12. N^{18}	13. N	14. N	14. B	16. N	16. B	17. N
1. B	0.45																															
2. N	0.23																															
2. B		0.37	0.15																													
3. N^{16}	0.45		0.36																													
3. B^{16}		0.61		0.28	0.66																											
3. N^{17}	0.38		0.25		0.36	0.30																										
3. B^{17}		0.61		0.25	0.67	0.75	0.20																									
4. N	0.48		0.14		0.38		0.40																									
4. B		0.38		0.15		0.30		0.38	0.29																							
5. N	0.35		0.49		0.46		0.12		0.31																							
6. N	0.55		0.20		0.46		0.34		0.47		0.39																					
7. N	0.42		0.27		0.38		0.27		0.41		0.43	0.54																				
7. B		0.57		0.51		0.41		0.42		0.32			0.59																			
8. N	0.30		0.43		0.32		0.32		0.23		0.22	0.36	0.37																			
8. B		0.40		0.36		0.46		0.36		0.25				0.36	0.55																	
9. N	0.41		0.34		**0.74**		0.24		0.32		0.41	0.47	0.32		0.33																	
10. N^{17}	0.02		0.00		0.07		0.00		0.00		0.04	0.09	0.04		0.05		0.14															
10. B^{17}		0.39		0.28		0.47		0.36		0.29				0.38		0.50		0.00														
10. N^{18}	0.30		0.00		0.11		0.30		0.33		0.13	0.24	0.33		0.05		0.08	0.00	0.20													
10. B^{18}		0.49		0.30		0.54		0.43		0.17				0.41		0.58		0.00	0.71	0.11												
11. B		0.33		0.15		0.48		0.43		0.17				0.24		0.50			0.50		0.67											
12. B^{16}		0.51		0.60		0.35		0.34		0.30				0.68		0.32			0.38		0.34	0.18										
12. B^{17a}		0.65		0.26		0.73		0.76		0.32				0.52		0.35			0.40		0.47	0.43	0.37									
12. N^{17b}	0.32		0.20		0.40		0.15		0.19		0.26	0.33	0.28		0.26		0.51	0.38		0.06			0.24	0.24								
12. N^{18}	0.23		0.00		0.07		0.15		0.20		0.13	0.24	0.33		0.04		0.05	0.00		**0.60**			0.09	0.09	0.04							
13. N	0.49		0.23		0.48		**0.62**		0.55		0.25	0.47	0.40		0.28		0.35	0.00		0.33					0.24	0.14						
14. N	0.23		**1.00***		0.36		0.25		0.14		0.49	0.20	0.27		0.43		0.34	0.00		0.00					0.20	0.00	0.23					
14. B		0.43		0.16		0.43		0.46		0.31				0.24		0.21			0.35		0.32	0.35	0.45	0.45				0.35				
16. N	**0.61**		0.30		**0.64**		0.21		0.47		0.53	0.49	0.40		0.30		**0.62**	0.07		0.17					0.38	0.12	0.36	0.30				
16. B		0.69		0.32		0.60		0.59		0.41				0.39		0.40			0.48		0.44	0.37	0.63	0.63					0.58	0.56		
17. N	0.51		0.35		**0.75**		0.26		0.44		0.55	0.52	0.39		0.30		**0.71**	0.06		0.12					0.34	0.09	0.42	0.35		**0.75**		
18. N	0.51		0.29		**0.63**		0.28		0.49		0.41	0.40	0.30		0.29		**0.62**	0.06		0.14					0.36	0.06	0.39	0.29		**0.76**		**0.67**

*Number of debris items recovered from nests on Adele Island and Rose Atoll was low, at only two per site.