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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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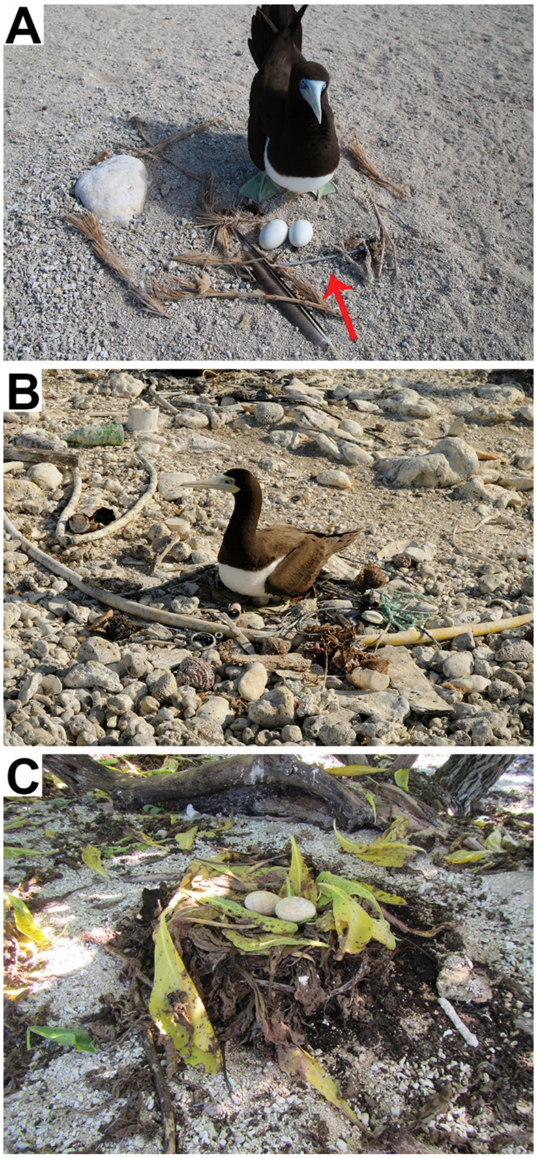

Fig. 1. The size of nests and the materials used by brown boobies varies greatly between and within sites. (A) A male brown booby on a sparse nest with one debris item (black cable tie, indicated by red arrow), Bedout Island, Timor Sea. (B) A female brown booby on a nest with a large assortment of debris 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