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Ingestion of marine debris by Wedge-tailed Shearwaters (*Ardenna pacifica*) on Lord Howe Island, Australia during 2005–2018

Jennifer L. Lavers[a,*], Ian Hutton[b], Alexander L. Bond[c]

[a] Institute for Marine and Antarctic Studies, University of Tasmania, 20 Castray Esplanade, Battery Point, Tasmania 7004, Australia
[b] Lord Howe Island Museum, P.O. Box 157, Lord Howe Island, New South Wales 2898, Australia
[c] Bird Group, Department of Life Sciences, The Natural History Museum, Akeman Street, Tring, Hertfordshire HP23 6AP, United Kingdom

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ABSTRACT

Annual rates of plastic production have been increasing rapidly since the 1950s. Inadequate or improper disposal of plastic products has contributed to a significant increase in plastic debris in the world's oceans and a corresponding increase in the number of species negatively affected by this debris. Here we investigate trends in the type, amount, and colour of ingested plastic over time, and determine whether ingested plastic contributes to reduced health of Wedge-tailed Shearwaters (*Ardenna pacifica*) on Lord Howe Island, Australia. The results show no clear influence of ingested plastic on body condition, while trends in the prevalence, number, and mass of plastic items ingested per bird during 2005 and 2013–2018 were more variable. There was some evidence adult birds are selecting plastic by colour. Future monitoring of this pan-tropical seabird would provide a unique opportunity to gather data from multiple sites, concurrently.

1. Introduction

First known as Bakelite, plastic was invented in 1907 (Baekeland, 1909), mass production began in the 1950s, increasing exponentially, and now reaches 335 million metric tonnes per year (PlasticsEurope, 2017). Plastics are designed to be light-weight, convenient, and durable, several characteristics that make them suitable packaging alternatives compared to other materials such as glass or metal, but also makes them problematic in the environment (Hopewell et al., 2009). Plastics are inexpensive to produce and widely consumed (UNEP, 2014). In Australia, 37% of plastic items comprise single-use packaging, leading to a significant increase in disposal rates in the last half century (PACIA, 2013).

Once in the ocean, plastic particles can both sink and float, becoming dispersed over long distances via tides and currents (Thiel et al., 2013). Significant quantities of plastic are now in all oceanic basins (Eriksen et al., 2014) and freshwater systems (Eerkes-Medrano et al., 2015), accounting for > 80% of debris items recorded at-sea, on beaches, and along river banks (Gregory and Ryan, 1997; Hammer et al., 2012). These synthetic materials persist for decades in the marine environment, posing a considerable threat to a diverse array of marine flora and fauna (Gall and Thompson, 2015).

In Australia, at least 77 marine species are known to be impacted by plastic debris, with Australian fur seals (*Arctocephalus pusillus doriferus*) and Flesh-footed Shearwaters (*Ardenna carneipes*) exhibiting some of the highest rates of entanglement and ingestion in the world, respectively (Ceccarelli, 2009; Lavers and Bond, 2016b; Lavers et al., 2014). Worryingly, entanglement and ingestion rates in both Australian pinnipeds and shearwaters are increasing (Lavers et al., in prep; Page et al., 2004) despite plastic debris being identified as a key threatening process in Australian legislation (DEWHA, 2014; Parliament of Australia, 2016) and the release of plastic into the marine environment prohibited under international law (MARPOL Annex V resolution MEPC.201(62)), to which Australia is a signatory. Under the *Convention on Biological Diversity 1992*, signatories (including Australia) have pledged to achieve the Aichi Biodiversity Targets, including that "by 2020, pollution has been brought to levels that are not detrimental to ecosystem function and biodiversity."

Interactions between wildlife and plastic debris can contribute directly to mortality through entanglement, or starvation and dehydration resulting from blockages, and damage to the digestive tract due to the ingestion of plastic (Gall and Thompson, 2015). The indirect, sublethal effects resulting from plastic debris are less well understood, but include exposure to toxins adhered to the surface of ingested plastic fragments (Lavers and Bond, 2016a; Lavers et al., 2014; Tanaka et al., 2015). The ingestion of significant quantities of plastic is also correlated with and contributes to reduced body condition (morbidity), with fledgling Flesh-footed Shearwaters exhibiting reduced wing length and

* Corresponding author.
E-mail address: Jennifer.Lavers@utas.edu.au (J.L. Lavers).

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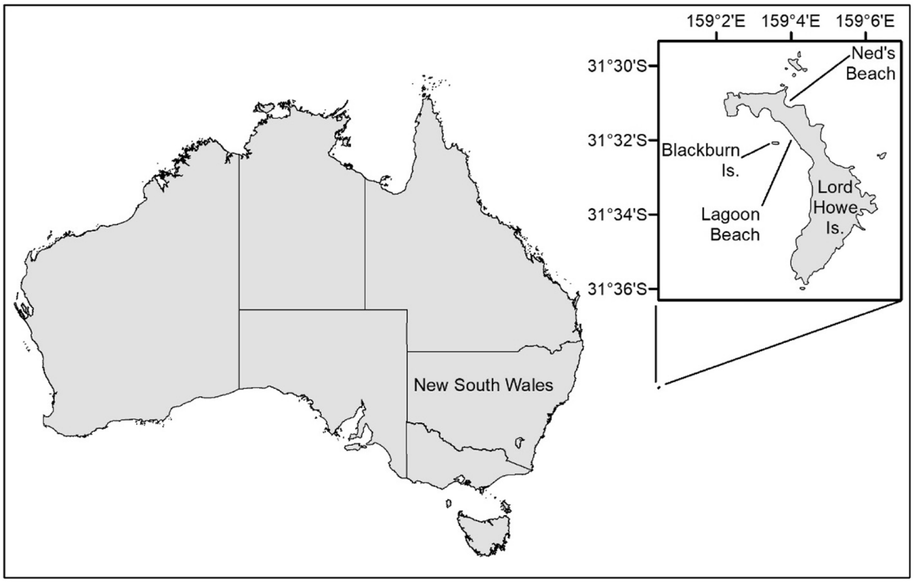

Fig. 1. Sampling sites for Wedge-tailed Shearwater (*Ardenna pacifica*) fledglings on Lord Howe Island during 2005 and 2013–2018.

body mass thought to reduced their survival by around 10% (Lavers et al., 2014).

Wedge-tailed Shearwaters (*Ardenna pacifica*) have been reported to ingest plastic in Australia (Hutton et al., 2008; Verlis et al., 2013) and elsewhere (Fry et al., 1987; Rapp et al., 2017), but the extent to which this may affect the health of individuals has not been investigated. Our goal was therefore to assess changes in the frequency of plastic ingestion by Wedge-tailed Shearwaters from eastern Australia collected during 2005 and 2013–2018, and to examine the relationship between plastic load and fledgling body condition.

2. Methods

2.1. Sampling birds

Wedge-tailed Shearwater fledglings (approximately 80 days old) were sampled on Lord Howe Island (31′31°S, 159′02°E), New South Wales, including an adjacent islet, from late-April until mid-May 2005 and 2013–2018 (Fig. 1). Fledglings of this species do not typically regurgitate a bolus and receive their final meal approximately two weeks before departing the nest (Baduini, 2002; Hutton et al., 2008). As such, it's unlikely that new plastic items would be accumulated by young birds during or after the sampling period.

Body mass (± 10 g) was determined using a spring balance, wing chord (flattened; ± 1 mm; to the tip of the longest primary feather) using a stopped ruler, and head + bill and culmen length using Vernier callipers (± 0.1 mm). Ingested plastic was collected by stomach flushing following procedures outlined by Duffy and Jackson (1986). In brief, seawater (approximately 90 ml) at ambient temperature was gently pumped into the proventriculus through a tube, thus displacing any food or plastic items. Once fluid and stomach contents began to flow back up the throat (i.e., once the stomach was completely filled), the bird was inverted over a container to collect anything expelled. Freshly dead (< 24 h) fledgling shearwater carcasses were collected from beaches adjacent to the colonies after unsuccessful fledging attempts (often a result of strong onshore winds) each morning. Birds were measured, weighed, and necropsied immediately upon collection.

Plastic items from each individual bird were dried and weighed separately to the nearest 0.001 g using an electronic balance and sorted by colour (white, blue, green, red/pink, yellow/orange, and black/grey/brown) and type following van Franeker and Law (2015) and Provencher et al. (2017): industrial pellets (nurdles) and user plastic (all non-industrial remains of plastic objects) differentiated into five subcategories including sheet-like plastics (e.g., bag and film), thread-like plastics (e.g., rope and line), foam (e.g., polystyrene), fragments (unidentifiable hard plastics), and other (e.g., balloon rubber, melted plastic).

2.2. Statistical methods

We first examined whether the prevalence, number of pieces, or mass of plastic varied among years using generalized linear models with binomial, Poisson, and normal error structures, respectively. We report the mean ± SD and range following Provencher et al. (2017). To test whether the mass of ingested plastic was related to individuals' body size, we used a general linear models and examined the relationship between ingested plastic mass, and birds' mass, culmen length, head + bill length, and wing chord length. We also compared the body mass of birds among years and between the two sampling methods (lavage of live birds, and necropsy of beach-washed dead birds) using general linear models.

We compared the composition of ingested plastics (in terms of colour and plastic type) among years using Jaccard's index of similarity, where values of $J = 0$ indicate complete dissimilarity, and $J = 1$ indicates identical composition; Values of $J > 0.60$ were considered to be significant overlap. Lastly, we conducted a power analysis to assess the sample size needed to detect a change (5%–100%; in 5% increments; with power of 80%) in the frequency of plastic ingestion by Wedge-tailed Shearwater fledglings over time, as described in van Franeker and Meijboom (2002). All statistical analyses were done in R 3.4.3 (R Core Team, 2018) using the packages *lme4* (Bates et al., 2015) and *vegan* (Oksanen et al., 2013); results from parametric tests were considered statistically significant when $p < 0.05$.

3. Results

We examined 224 Wedge-tailed Shearwater fledglings for plastic debris (lavage: $n = 154$; necropsy: $n = 70$) during 2005 and 2013–2018 (Table 1). Overall, 35.2% of fledglings sampled during 2013–2018 contained 1.07 ± 3.21 pieces of plastic weighing 0.086 ± 0.256 g (Table 1) compared to 46% of lavaged birds sampled in 2005 ($n = 30$). The frequency of occurrence of plastic was 31.2% for lavaged birds, and 44.3% for necropsied birds, the mean number of pieces was 1.01 ± 3.68 and 1.04 ± 1.76, respectively, and the mass of ingested