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Regional differences in plastic ingestion among Southern Ocean fur seals and albatrosses

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ABSTRACT

We provide data on regional differences in plastic ingestion for two Southern Ocean top predators: *Arctocephalus* fur seals and albatrosses (Diomedeidae). Fur seals breeding on Macquarie Island in the 1990s excreted small (mainly 2–5 mm) plastic fragments, probably derived secondarily from myctophid fish. No plastic was found in the scats of these seals breeding on three islands in the southwest Indian and central South Atlantic Oceans, despite myctophids dominating their diets at these locations. Compared to recent reports of plastic ingestion by albatrosses off the east coast of South America, we confirm that plastic is seldom found in the stomachs of *Thalassarche* albatrosses off South Africa, but found no *Diomedea* albatrosses to contain plastic, compared to 26% off South America. The reasons for such regional differences are unclear, but emphasize the importance of reporting negative as well as positive records of plastic ingestion by marine biota.

1. Introduction

There is mounting concern about the pervasive nature of plastic in the diets of marine organisms, and recent reviews highlight the growing proportions of species affected by this problem (Kühn et al., 2015; Wilcox et al., 2015). Plastic ingestion is widespread in seabirds, but the incidence (frequency of occurrence) and average plastic load per individual (by number and mass) varies considerably among species in relation to the balance between the rates of ingestion and regurgitation-excretion, as well as regional differences in exposure to plastic debris at sea (Ryan, 2015). Temporal comparisons within species typically have shown changes in the composition of ingested plastic, but few strong trends in the incidence or amount of plastic ingested per individual over the last few decades (e.g. Vlietstra and Parga, 2002; Ryan, 2008). Perhaps the most compelling evidence of regional differences in plastic ingestion linked to the risk of exposure to plastics in the environment comes from the northern fulmar *Fulmarus glacialis*, which shows a marked decrease in plastic ingestion rates with increasing latitude (and hence distance from major human population centres) in both the North Atlantic and North Pacific Oceans (reviewed by van Franeker and Law, 2015). However, relatively few of such comparisons of plastic ingestion rates have been made among populations sampled in different regions over the same period. In this paper we report regional differences in plastic ingestion for two groups of Southern Ocean top predators: *Arctocephalus* fur seals and albatrosses (Diomedeidae).

Twelve of 32 seal species have been recorded to ingest plastic at least occasionally (Kühn et al., 2015), but seals generally are more often entangled in debris than affected by ingestion (Laist, 1997; but see Bravo Rebolledo et al., 2013). One of the few studies to record plastic in seal diets is Eriksson and Burton (2003), who described 164 plastic particles in the excreta of Antarctic fur seals *Arctocephalus gazella* and Subantarctic fur seals *A. tropicalis* breeding on Macquarie Island, a sub-Antarctic island (55°S) south of New Zealand. The ingested plastic was mainly small items (99% were <10 mm long), but despite being mainly in the size range of industrial pellets, all were fragments of larger items. Many had been worn smooth, and given their small size they were thought to have derived secondarily from prey species, most likely myctophid fish (Eriksson and Burton, 2003). Myctophid fish dominate the diet of these seals at Macquarie Island (Goldsworthy et al., 1997), and are known to ingest plastic, especially in subtropical gyres where floating litter tends to accumulate (e.g. Boerger et al., 2010; Davison and Asch, 2011), but also in areas away from gyres (Van Noord, 2013). We compare these findings with data collected at three other breeding colonies of these seals: Marion Island (47°S), which has both Antarctic and Subantarctic fur seals, and Tristan da Cunha (37°S) and Gough Island (40°S), which have only Subantarctic fur seals. All three islands lie farther north than Macquarie Island, and in the case of Tristan da Cunha, is fairly close to the South Atlantic gyre where floating debris

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accumulates (Cózar et al., 2014; Eriksen et al., 2014; Ryan, 2014). We thus expect a higher incidence of ingested plastic in seals from these sites than at Macquarie Island.

Among the albatrosses (Diomedeidae), the incidence of ingested plastic is generally quite low with the exception of the two common North Pacific species (Laysan *Phoebastria immutabilis* and Black-footed *P. nigripes* albatrosses), which have high incidence of ingestion (Gray et al., 2012), particularly among their chicks (Fry et al., 1987). However, a recent paper by Jiménez et al. (2015) reported that 26% of *Diomedea* albatrosses killed by fishing gear off the east coast of South America contained plastic or other marine debris. We compare these findings with data collected from albatrosses killed by fishing gear off South Africa over the same period. Both sample areas are close to continental source areas with large human populations so we expect similar rates of debris ingestion off Africa and South America.

2. Materials and methods

2.1. Fur seal scats

MNB, PJNdB and experienced field assistants trained new field assistants to collect and process fur seal scats from Subantarctic and Antarctic fur seal colonies on Marion Island (46°54′S, 37°45′E) each year from 1989 to 2014. Fresh scats were placed individually in plastic bags and stored frozen until they were processed. In the laboratory, field assistants washed each scat through a 0.5 mm sieve under running water to collect undigested prey remains, principally fish otoliths, squid beaks and crustacean exoskeleton remains (see Klages and Bester, 1998; Makhado et al., 2008, 2013 for further details). Prey remains were examined under a dissecting microscope. The same methodology as that used by Goldsworthy et al. (1997) to collect plastic fragments in fur seal scats at Macquarie Island (Eriksson and Burton, 2003). Plastic items were explicitly searched for from 2006, following the publication of Eriksson and Burton (2003). Prior to that they are unlikely to have been overlooked because they superficially resemble otoliths, and almost half of Eriksson and Burton's (2003) samples were brightly coloured (red, blue, green, etc.) and would have been highly visible.

Fur seal scats collected from the Caves, Tristan da Cunha (37°10′S, 12°19′W) and beaches along the southeast coast of Gough Island (40°21′S, 9°53′W) from 2012 to 2013 (*A. tropicalis*) were processed at the University of Pretoria under MNB's direct supervision, using the same approach.

2.2. Albatross stomach contents

PGR examined albatrosses killed on pelagic long-lines off South Africa from 2005 to 2015. Foreign-flagged vessels fishing under licence in South African waters for tunas (*Thunnus* spp.) and swordfish (*Xiphias gladius*) are required to carry an independent fishery observer and part of their responsibilities includes returning all seabirds killed to port for examination (Petersen et al., 2009). Carcasses were frozen prior to examination. The contents of the proventriculus and ventriculus were examined separately for all birds. Stomach contents were washed into a tray and agitated to separate prey remains. Plastic items are readily detected because almost all items ingested by seabirds float, and those that do not are less dense than other hard prey remains (bones, otoliths, squid beaks), and thus move more readily when the sample is stirred. This was the approach used by Ryan (1987) to detect plastic in the stomach contents of a wide range of seabirds.

Some authorities split shy *Thalassarche cauta* and white-capped albatrosses *T. steadi*, but they are only separable with genetic markers. Birds killed on long-lines off South Africa are approximately 95% *T.* [*c.*] *steadi* (Hockey et al., 2005). Similarly, not all royal albatrosses *Diomedea epomophora/sanfordi* could be assigned to species level with certainty, and so they were lumped together (although some individuals of both species were caught). Tristan *D. dabbenena* and wandering *D. exulans* albatrosses were separated based on measurements of birds sexed by inspection of their gonads (Cuthbert et al., 2003).

3. Results

3.1. Fur seals

No plastic items were found in any seal scats, despite myctophid fish dominating the diets of fur seals at all three sampling sites (Table 1). Only modest numbers of Subantarctic fur seal scats were examined from Tristan da Cunha and Gough Islands, but sampling was much more extensive at Marion Island, where an average of 193 ± 183 Subantarctic fur seal scats per year (n = 25 years) and 148 ± 123 Antarctic fur seal scats per year (n = 22 years) were examined spanning the period sampled by Eriksson and Burton (2003). More than 70% of scats (74.2% of Antarctic fur seal and 70.7% of Subantarctic fur seal scats) were sampled from 2006 to 2014, after plastic items were searched for explicitly. At Macquarie Island, Eriksson and Burton (2003) found 45 plastic particles (1 per scat) in 138 scat samples collected in 1990/91 (they do not report the number of scats examined in 1996/97 of which 100 contained a further 119 particles; Eriksson and Burton, 2003). The sample size for Marion Island in 1990/91 was 137 scats (63 Antarctic and 74 Subantarctic fur seals), so even restricting the comparison to this year alone, the absence of plastic in seal scats from Marion Island was significantly less than in scats from Macquarie Island ($\chi^2 = 51.06$, df = 1, $P < 0.001$).

3.2. Albatrosses

The stomach contents of 868 albatrosses killed on long-lines off South Africa were examined for ingested plastic (Table 2). Shy albatrosses were the most frequently killed (69% of all albatrosses), and were the only taxon to contain ingested marine debris (n = 16). Most shy albatrosses (n = 13) contained fishing hooks and snoods (the lines carrying hooks) that had been ingested prior to the capture that killed the bird (Table 1). All but one hook/snood were typical of the hake *Merluccius* spp. long-line fishery off South Africa (e.g. Barnes et al., 1997). Three individuals contained multiple hooks, with a maximum of three hooks in one bird, and 15 of the 16 hake snoods still had intact hooks. Excluding fishing gear, only three shy albatrosses had ingested plastic (0.5%); two contained single fragments of hard plastic (~10 and 13 mm long), and one contained a ball ~8 mm in diameter of apparently largely synthetic fibres (including many strongly-coloured fibres).

The incidence of debris ingestion among *Thalassarche* albatrosses was low off both South Africa and South America. However, despite the small sample sizes, it is unlikely that the great albatrosses *Diomedea* examined from the South African fishery (0 of 15 with ingested debris) had the same incidence of ingested plastic as those killed off South America (26%, $P = 0.012$, binomial exact probability).

Table 1
Number of fur seal scats with identifiable prey remains examined at sub-Antarctic and temperate islands in the south Atlantic and southwest Indian Ocean, and the proportion of myctophid fish in their diet (by number of items).

Species and location	*n* Sampled	Years	% Myctophid fish in diet
Subantarctic fur seal *Arctocephalus tropicalis*			
Tristan da Cunha	38	2012–2013	92%
Gough Island	54	2012–2013	98%
Marion Island	4813	1989–2014	99%
Antarctic fur seal *Arctocephalus gazella*			
Marion Island	3253	1989–2014	95%

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