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

Peter G. Ryan[1,*], P.J. Nico de Bruyn[2] and Marthán N. Bester[2]

[1]*Percy FitzPatrick Institute of African Ornithology, DST/NRF Centre of Excellence, University of Cape Town, Rondebosch 7701, South Africa*

[2]*Mammal Research Institute, Department of Zoology and Entomology, University of Pretoria, Private Bag X20, Hatfield 0028, Pretoria, South Africa*

*E-mail: pryan31@gmail.com

Phone +27 21 6502966; Fax +27 21 6503295

Highlights

- We report regional differences in plastic ingestion among S Ocean top predators.
- South Atlantic and SW Indian Ocean fur seals do not excrete plastic particles.
- *Diomedea* albatrosses from S Africa contain less plastic than those from S America.
- It is important to report negative records of plastic ingestion by marine biota.

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 emphasise the importance of reporting negative as well as positive records of plastic ingestion by marine biota.

Keywords: marine debris; *Arctocephalus*; *Diomedea; Thalassarche*; Marion Island; Tristan da Cunha

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 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, 2012). 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 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 the 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 license 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

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%

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 – 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 (χ^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

Table 2. Plastic ingestion by albatrosses off South Africa compared to those off the east coast of South America (from Jiménez et al., 2015).

Species	South Africa		South America	
	n	%	n	%
Wandering albatross *Diomedea exulans*	4	0%	12	0%
Tristan albatross *D. dabbenena*	5	0%	6	33%
Royal albatrosses *D. epomophora/sanfordi*	6	0%	60	30%
Total for *Diomedea* albatrosses	15	0%	78	26%
Shy albatrosses *Thalassarche cauta/steadi*	601	2.7%	17	0%
Black-browed albatross *T. melanophris*	157	0%	32	3%
Atlantic yellow-nosed albatross *T. chlororhynchos*	18	0%	1	0%
Indian yellow-nosed albatross *T. carteri*	77	0%	0	–
Total for *Thalassarche* albatrosses	853	1.9%	50	2%

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).

4. Discussion

Our sampling methods for ingested plastic used the same approaches as those used by Eriksson and Burton (2003) for *Arctocephalus* fur seals (although assistants were not explicitly instructed to look for ingested plastics when processing scats prior to 2006), and by Jiménez et al. (2015) for *Diomedea* and *Thalassarche* albatrosses, so methodological biases should not have influenced our comparisons among studies. Sampling also spanned the same period for fur seals at Marion Island as those at Macquarie Island, and for albatrosses off South Africa and South America, so any differences in plastic ingestion should reflect regional differences in plastic exposure rather than long-term trends in the abundance of plastic at sea. Ingested plastic loads – both the number and mass of ingested plastic items – are highly variable among individuals, and typically strongly left skewed (a few individuals contain most ingested plastic). This skew limits the power to detect differences among populations, but the incidence (frequency of occurrence) of ingested plastic provides a simple indication of differences among populations. We expected that there should be no regional difference in plastic incidence among albatrosses, and this was supported for *Thalassarche* albatrosses, but fewer *Diomedea* albatrosses contained plastic off Africa than South America. The reason for this apparent regional difference is unclear. At South Georgia, wandering albatrosses contain more plastic than *Thalassarche* albatrosses (Phillips et al., 2010), reflecting the greater proclivity of *Diomedea* albatrosses to ingest debris (Jiménez et al., 2015). However, no wandering albatrosses sampled at sea contained debris (Jiménez et al., 2015; this paper).

The low incidence of plastic in *Thalassarche* albatrosses appears typical for this genus (Colabuono et al., 2009; Phillips et al., 2010). Ryan (1987) reported 2 of 18 (11%) black-browed albatrosses *T. melanophris* collected in South Africa during the early 1980s contained plastic, but both birds to do so were stranded during stormy weather, potentially influencing their likelihood of eating unusual items (Ryan 1987). The incidence of plastic ingestion is Southern Ocean albatrosses is much lower than that in North Pacific species sampled in the same way (64%; Gray et al., 2012). Most of the debris found in *Thalassarche* albatrosses is fishing line and hooks (Colabuono et al., 2009; Phillips et al., 2010; this paper), presumably obtained while scavenging at fishing vessels. The proportion of hake snoods with intact hooks found in shy albatrosses killed off South Africa was significantly higher than white-chinned petrels *Procellaria aequinoctialis* caught by the same fishing vessels (16 of 38, Ryan, 2015; $\chi^2 = 11.26$, df = 1, $P < 0.01$), suggesting that either the petrels digest hooks more rapidly than albatrosses, or that albatrosses are able to regurgitate hooks or snoods. The latter explanation is more plausible, because hooks and snoods are often found next to albatross nests (e.g. Nel and Nel, 1999; Phillips et al., 2010). Our results suggest that it is not just adult albatrosses feeding chicks that are able to regurgitate hooks and snoods, but that birds at sea also can do so; adults make up only 14% of shy albatrosses sampled, yet 4 of 13 birds containing hooks or snoods were adults, indicating no bias against adults containing these items (which would be the case if offloading to chicks was the main mechanism for losing ingested hooks and snoods). If albatrosses are able to regurgitate ingested plastic at sea, they are likely to be less susceptible to the damaging impacts of plastic ingestion than are petrels and other bird species that tend to retain ingested plastic for long periods (Ryan, 2015; although the chicks of some albatrosses clearly are impacted when fed large plastic loads by their parents; Sileo et al., 1990).

Among fur seals, we expected animals from Macquarie Island, the southernmost colony sampled at close to 55°S, to contain less plastic than animals from colonies farther north because marine debris decreases with increasing latitude in the Southern Ocean (Barnes et al., 2010; Ryan et al., 2014). In particular, we expected seals from Tristan da Cunha, which lies just south of the South Atlantic gyre at 37°S, to be exposed to more plastic than seals breeding farther south – especially because the Tristan samples are more recent (2012 and 2013), and there is evidence of high densities of small plastic particles in this region (Cózar et al., 2014; Eriksen et al., 2014). However, no plastic was reported in seal scats at any of the three islands studied (Klages and Bester, 1998; Makhado et al., 2008, 2013; this paper).

The only records of plastic ingestion by myctophid fish come from the northern hemisphere (Boerger et al., 2010; Davison and Asch, 2011; van Noord, 2013), but there is no reason not to expect these fish to also ingest at least some plastic in the south. Myctophid fish dominate the diets of both Antarctic and Subantarctic fur seals at the three sites studied (Table 1; Klages and Bester, 1998; Makhado et al. 2008, 2013), so the absence of plastic in fur seal scats from Marion, Tristan and Gough is surprising given the apparently regular occurrence of plastic in scats of the same species at Macquarie Island (Eriksson and Burton 2003), unless the ingestion of plastics by myctophids is species specific. The identification of myctophid otoliths in the scats of fur seals at Tristan and Gough Islands is still ongoing, but at Marion Island their diet differs from that at Macquarie. In summer *Protomyctophum bolini* and *Gymnoscopelus piabilis* dominate the diet of *A. tropicalis* at Marion Island (Makhado et al., 2013) and *G. piabilis* and *Krefftichthys anderssoni* the diet of *A. gazella* (Makhado et al., 2008), whereas *Electrona subaspera* is by far the most frequently taken at Macquarie Island in summer by both fur seal species (Robinson et al., 2002). To date, no members of these four genera have been recorded to contain ingested plastic (Boerger et al., 2010; Davison and Asch, 2011; van Noord, 2013).

We have no simple explanation for the regional differences in ingestion rates reported in this study, but the differences emphasize the importance of reporting data where plastic ingestion is not found to occur. Attempts to review and model the incidence of plastic ingestion by marine organisms (e.g. Schuyler et al., 2015; Wilcox et al., 2015) depend critically on negative as well as positive records of plastic ingestion. We strongly encourage researchers to report all records of organisms checked for debris ingestion, irrespective of whether any debris is found or not.

Acknowledgements

We thank the many laboratory and field assistants and fishery observers who collected samples and examined faecal contents or assisted with seabird autopsies. The project was part of the South African National Antarctic Programme, with financial support from the National Research Foundation and the Universities of Cape Town and Pretoria.

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