Environmental Pollution xxx (2015) 1–3

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Commentary

# How quickly do albatrosses and petrels digest plastic particles?

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A R T I C L E I N F O

*Article history:*
Received 22 June 2015
Received in revised form
1 August 2015
Accepted 5 August 2015
Available online xxx

*Keywords:*
Plastic ingestion
Seabirds
Wear rate
Retention time
Regurgitation
Inter-generational transfer

A B S T R A C T

Understanding how rapidly seabirds excrete or regurgitate ingested plastic items is important for their use as monitors of marine debris. van Franeker and Law (2015) inferred that fulmarine petrels excrete ~75% of plastic particles within a month of ingestion based on decreases in the amounts of plastic in the stomachs of adult petrels moving to relatively clean environments to breed. However, similar decreases occur among resident species due to adults passing plastic loads to their chicks. The few direct measures of wear rates and retention times of persistent stomach contents suggest longer plastic residence times in most albatrosses and petrels. Residence time presumably varies with item size, type of plastic, the amount and composition of other persistent stomach contents, and the size at which items are excreted, which may vary among taxa. Accurate measures of ingested plastic retention times are needed to better understand temporal and spatial patterns in ingested plastic loads within marine organisms, especially if they are to be used as indicators of plastic pollution trends.



## 1. Introduction

Plastic ingestion is generally considered to be a more serious problem for marine animals than entanglement in marine debris because large proportions of populations are affected (Gall and Thompson, 2015; Kühn et al., 2015). Among seabirds, the albatrosses and petrels (Procellariiformes) have particularly high incidences of ingestion, with many species having plastic in more than half of all individuals examined (e.g. Laist, 1997; Kühn et al., 2015). This is because albatrosses and petrels seldom regurgitate indigestible items and in the case of the petrels, their narrow, acutely angled pyloric sphincter traps indigestible prey remains, including plastic particles, in the muscular ventriculus or hindstomach (Furness, 1985). Albatrosses and petrels probably ingest less plastic than e.g. urban gulls Laridae, but gulls don't accumulate plastic in their stomachs because they rapidly regurgitate indigestible items. The high incidence of ingested plastic in albatrosses and petrels has resulted in them being used to monitor changes in the abundance and composition of floating marine debris (e.g. Ryan et al., 2009; van Franeker et al., 2011).

In order to interpret spatial and temporal changes in plastic ingestion by albatrosses and petrels, we need to understand the retention time of plastic particles in their stomachs (Ryan et al., 2009). To date it has been assumed that, in the absence of regurgitation, plastic particles are retained for at least 3–6 months before they wear down sufficiently to pass through the pyloric sphincter into the small intestine (Day et al., 1985; Ryan, 1988; Ainley et al., 1990; Spear et al., 1995). However, there are few direct data to support this view (Ryan and Jackson, 1987). Recently, van Franeker and Law (2015) suggested that plastic particles pass much more rapidly through the stomachs of fulmarine petrels, with perhaps 75% of hard plastic items eroded to the point where they can be passed into the intestine and excreted within a month. They based this conclusion on the fact that adult petrels breeding in relatively 'clean' environments – Antarctica and Arctic Canada – lose plastic rapidly over the breeding season (van Franeker and Bell, 1988; Mallory, 2008). In this commentary I summarise the data showing that at least some albatrosses and petrels retain plastic items in their stomachs for many months, and advocate caution in assuming this rapid turnover applies to all procellariiform seabirds.

## 2. Results and discussion

### 2.1. Inter-generational transfer

A decrease in plastic loads over the breeding season typically occurs in adult petrels irrespective of the environments where they forage, because breeding petrels feed accumulated plastics to their chicks (Ryan, 1988; Carey, 2011; Rodríguez et al., 2012). This inter-generational transfer of accumulated plastic loads results in a steady decrease in adult plastic loads over the breeding season

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http://dx.doi.org/10.1016/j.envpol.2015.08.005
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(Skira, 1986). For example, plastic loads in white-faced storm petrels *Pelagodroma marina* breeding at the Tristan archipelago can be tracked in the prey remains left by subantarctic skuas *Stercorarius antarcticus* (Ryan, 2008). The adult storm petrels exhibit a rapid decrease in adult plastic loads after their chicks hatch, then a gradual increase after chick feeding ceases (Fig. 1; P.G. Ryan, unpubl. data). This storm petrel population is resident in the central South Atlantic Ocean, so the pattern over the breeding season cannot be ascribed to movement to 'cleaner' environments.

van Franeker and Law (2015) didn't discuss the inter-generational transfer of plastics as an explanation for the rapid decrease in plastic loads (and other indigestible prey remains such as squid beaks) in fulmarine petrels breeding at high latitudes because they observed decreases in plastic loads in Cape petrels *Daption capense* before the birds' chicks hatched, which does indeed support their claim that plastic loss is rapid in this species. However, in their supplemental material, van Franeker and Law (2015) note that chicks of Wilson's storm petrels *Oceanites oceanicus* in the Antarctic contain more plastic than breeding adults collected at the same location, suggesting that wear rates are lower in this species. They suggest that adult storm petrels stored these particles in the proventriculus (fore-stomach), not the muscular ventriculus, and thus were subjected to little mechanical wear. This is unlikely because virtually all plastic occurs in the ventriculus of petrels and storm petrels (Furness, 1985; Ryan, 1987; Spear et al., 1995). The argument that the longer retention time resulted in smaller plastic particles in the storm petrels relative to fulmars is spurious, because the much smaller storm petrels (<10% of the mass of fulmars) ingest smaller plastic items (Furness, 1985; Ryan, 1987).

### 2.2. Factors affecting retention times

Three factors influence the time plastic items remain in seabird stomachs in the absence of regurgitation: the initial size of the ingested particle, the rate of wear in the stomach, and the size of particles that pass into the intestine and are excreted. The size of plastic items ingested varies greatly within species, but the mean size correlates with body size among seabirds (Ryan, 1987). We might expect the threshold below which particles become small enough to pass into the intestine also scales with body size, at least among species with similar gut morphology. Most evidence suggests that only minute solid items are excreted by procellariiforms (e.g. Furness et al., 1984; Day et al., 1985). However, there may be some variation among species. For example, *Thalassarche* albatrosses excrete no visible particulate remains (Furness et al., 1984) despite their much larger size than fulmars and their less constricted gut morphology (Furness, 1985). However, Sileo et al. (1990) found plastic items in the intestines of some *Phoebastria* albatrosses, although they don't report the size of these items. Northern fulmars *Fulmarus glacialis* apparently excrete plastic particles with diameters <2 mm (van Franeker and Law, 2015), whereas white-chinned petrels *Procellaria aequinoctialis*, which are appreciably larger than fulmars and have a similar stomach morphology, frequently contain plastic items < 1 mm in their stomachs (Ryan, 1987; unpubl. data). The ability to excrete relatively large items could account for the seemingly faster turnover of plastic in fulmarine petrels (although the modal size class of plastic items in Cape petrels also is < 2 mm; Ryan, 1987).

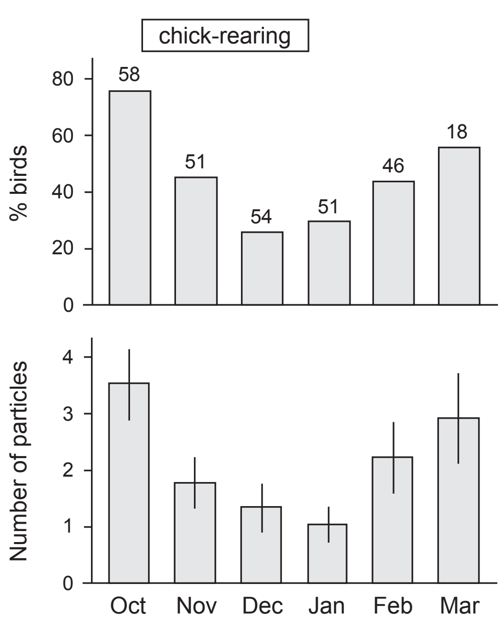


**Fig. 1.** Seasonal changes in the incidence of ingested plastic (% of birds containing plastic, with sample size per month in top panel) and average plastic load (number of particles per individual ± 1 SE in bottom panel) in white-faced storm petrels killed by subantarctic skuas on Inaccessible Island in 1989/90 in relation to the storm petrel's chick-rearing period at this site (see Ryan, 2008 for details).

### 2.3. Estimating wear rates

Day et al. (1985) proposed that the rate at which ingested plastic items wear down varies with the type of plastic and the amount of indigestible remains in the ventriculus (squid beaks, pumice and grit, as well as plastic items). However, there are few empirical data on plastic wear rates. Most studies have simply inferred wear rates from changes in the size or 'wear status' of pellets collected from random sets of birds sampled at different times (Day et al., 1985; Ainley et al., 1990; Spear et al., 1995) or from comparisons of the sizes of items in the stomachs of breeding adults and their chicks (Ryan, 1988). The only direct measure comes from polyethylene pellets fed experimentally to white-chinned petrel fledglings. The pellets, which averaged 35 mg (diameter ~5 mm), lost only 1.1% of their mass after 12 days (Ryan and Jackson, 1987). Even allowing for the fact that only about half of the pellets were in the ventriculus, and rates of wear may increase as particles get smaller (Ainley et al., 1990), it is hard to see how pellets could be eroded to the point where they are small enough to be excreted within a month (they would have to lose more than 90% of their mass before they were small enough to excrete, given that the modal particles size of plastic items in this species is < 4 mg; Ryan, 1987). The pellets used in this experiment were collected from beaches, and thus were deemed equivalent to pellets ingested by the petrels at sea in terms of age and wear.

Further evidence of long retention times for indigestible items come from adult Laysan albatrosses *Phoebastria immutabilis*, which kept small, plastic-coated devices in their stomachs for 50 days before feeding them to their chicks (Pettit et al., 1981). The devices were then retained by the chicks for at least 31 days, and probably >4 months (Pettit et al., 1981). *Thalassarche* albatrosses also retain squid beaks in their stomachs for more than 50 days (Furness et al., 1984). Monofilament lines are found in the stomach contents of both albatrosses and petrels long after the fishing hooks they carried have been completely digested. These seabirds scavenge fishery wastes, including fish heads from long-line vessels that are sometimes discarded with hooks and lines still attached. Off South Africa, albatrosses and petrels scavenging at hake long-line boats often consume 5/0 J-hooks (51 × 19 mm, 2.3 mm diameter steel shanks). Each hook is carried on a distinctively shaped, short monofilament snood. Some of these birds are subsequently killed when they are caught on much larger hooks set for tunas, allowing the stomach contents of large samples of birds to be examined (e.g. Ryan, 2008). Of 1909 white-chinned petrels examined from 1999 to 2014, 16 contained complete hake hooks and lines, two had partly digested hooks and lines, and 20 had lines where the hooks had been completely digested (P.G. Ryan, unpubl. data). Based on the ratio of intact hooks to partly and completely digested hooks, it is clear that the hooks take a considerable time to be digested – yet the monofilament lines remain intact much longer than the hooks, despite most lines being in the ventriculus. Although some monofilament lines show evidence of wear, there is no difference in the diameter of lines with hooks ($1.06 \pm 0.08$ mm, $n = 12$) and those without hooks ($1.04 \pm 0.10$ mm, $n = 14$, $t_{24} = 0.587$, 1-tailed $P = 0.281$).

## 3. Conclusions

Additional direct measures are needed of retention times of different types of plastic particles in the stomachs of seabirds in particular, and marine organisms more generally, in order to better understand temporal and spatial patterns in ingested plastic loads within species. It is possible that pellets wear more slowly than fragments of manufactured items for two reasons: 1) pellets are compact, cylindrical or near-spherical objects and thus inherently stronger than fragments of sheet plastic, and 2) fragments might be predisposed to break down because they presumably have been degrading due to e.g. UV exposure for some time to have become fragments in the first place. As a result, the shift in the composition of plastic ingested by seabirds from pellets to plastic fragments (e.g. Ryan, 2008; van Franeker et al., 2011; van Franeker and Law, 2015) may have accelerated the rate of plastic turnover. Such an effect would compromise to some extent attempts to use ingested plastic loads as indicators of environmental conditions.

## Acknowledgements

Research on plastics ingestion has been conducted with the support of the South African National Antarctic Programme. I thank Jan van Franeker and two anonymous referees for substantially improving this paper.

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Please cite this article in press as: Ryan, P.G., How quickly do albatrosses and petrels digest plastic particles?, Environmental Pollution (2015), http://dx.doi.org/10.1016/j.envpol.2015.08.005