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Plastic ingestion in seabirds of the western Indian Ocean

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ABSTRACT

We investigated seabird plastic ingestion in the western Indian Ocean by analyzing the stomach contents of 222 individuals belonging to nine seabird species (including two endangered species endemics to Reunion Island). The most affected species were tropical shearwaters (79%) and Barau's petrels (59%). The average number of plastic particles per contaminated bird was higher in Barau's petrels (6.10 ± 1.29) than in tropical shearwaters (3.84 ± 0.59). All other studied species also showed plastic presence in their stomach contents. The mass of plastic particles was significantly higher both in juvenile's Barau's petrels and tropical shearwaters than in adults. These results demonstrate the foraging areas of seabirds of the western Indian Ocean have a high level of plastic pollution. In Reunion Island, hundreds of tropical shearwaters and Barau's petrels are attracted by urban lights and die each year. We suggest taking advantage of this situation by using these species as long-term indicators of plastic marine pollution in the region.

1. Introduction

The increasing rate of plastic pollution in the oceans worldwide is well documented (Derraik, 2002; Plastics Europe, 2013; Wilcox et al., 2015) with concentrations of plastic fragments up to 580,000 pieces per square kilometre (Barnes et al., 2009). This emerging pollution is now a major threat to marine wildlife, and this includes entanglement, ingestion and chemical contamination. Ingestion of plastic by marine fauna has been reported all around the world (Derraik, 2002; Talsness et al., 2009; Verlis et al., 2014) and affects a large number of seabirds including albatrosses, petrels, shearwaters, seagulls and boobies (Azzarello and Van Vleet, 1987; Van Franeker and Law, 2015). The consequences of plastic ingestion by seabirds include stomach obstruction and internal wounds resulting in low body conditions and death (Ryan, 1988). Plastic ingestion can also impact the physical condition of the bird, reduce their reproduction potential and cause mortality due to toxins transfer (Teuten et al., 2009; Lavers et al., 2014). However the effects of plastic can vary among species, as some species have the ability to regurgitate (e.g., skuas, albatross) thus limiting undesired effects (Azzarello and Van Vleet, 1987). The species with a low capacity of regurgitation, except when feeding youngs (e.g., petrels), are particularly susceptible to plastic accumulation (Fumess, 1985). The effects of plastic ingestion can also vary in terms of residence time in seabirds' gastro-intestinal tracks depending on the size of the ingested items, the type of plastic and also the quantity and composition of other elements in birds stomachs (Ryan, 2015). Most of the studies on plastic ingestion realized so far have been focusing on the northern hemisphere (Yamashita et al., 2011; Avery-Gomm et al., 2012; Van Franeker and Law, 2015), but also in South Africa (Ryan, 1987; Ryan et al., 2016), South America (Copello and Quintana, 2003) and around eastern Australia (Lavers et al., 2014; Gilbert et al., 2016). Only few studies have been focusing on the tropical areas and all of them were realized in the Pacific Ocean (Spear et al., 1995; Verlis et al., 2014; Verlis et al., 2018).

So far no information has been published on plastic ingestion rates by seabirds in the western Indian Ocean. A few studies have shown plastic concentration in the water column (Barnes, 2004), on the beaches (Duhec et al., 2015; Bouwman et al., 2016) and on marine turtles (Hoarau et al., 2014). In this study we analyzed plastic ingestion in nine seabird species breeding or foraging at Reunion Island and at Juan de Nova (Mozambique Channel), among which two species are endemic and endangered (the Barau's petrel, *Pterodroma baraui*) or critically endangered (the Mascarene petrel, *Pseudobulweria aterrima*). The four other breeding species of Reunion were included in the study: the tropical shearwater (*Puffinus bailloni*), the wedge-tailed shearwater (*Ardenna pacifica*), the white-tailed tropicbird (*Phaethon lepturus*) and the brown noddy (*Anous stolidus*). We also included the lesser noddy (*Anous tenuirostris*), which does not breed in Reunion but which use the island

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as a roosting place during its post-breeding migration, probably originating from nearby Mauritius or Seychelles populations. Finally we also included the sooty tern (*Ornithoprion fuscatus*) from Juan de Nova as it is one of the most abundant and widespread species of the region and of the tropical oceans as a whole (Feare et al., 2007) as well as two Cape Gannets (*Morus capensis*) found in Reunion Island and probably originating from South Africa.

2. Methods

All samples used for this study were found dead in Reunion Island or Juan de Nova. Petrels and shearwaters from Reunion Island are attracted by urban lights and a large scale rescue program has been conducted since 1996 by the Société d'Etudes Ornithologique de La Réunion (SEOR) to monitor the number of birds affected and find solutions to reduce the impact (Le Corre et al., 2002; Salamolard et al., 2007; Gineste et al., 2017; Rodriguez et al., 2017). The vast majority of the birds found are rescued and released safely but 10% die as a consequence of fatal injuries. We used these dead birds for plastic ingestion analysis. Similarly, seabirds affected by light pollution have previously been used to perform plastic ingestion studies in the Canary Islands (Rodriguez et al., 2012) and a recent study has demonstrated the interest of using birds disoriented by light for such a monitoring (Rodriguez et al., 2017). Other seabird species are regularly found by people and brought to the wildlife rescue center of the SEOR. These birds are generally injured or weakened by bad weather or marine conditions. Some birds are rehabilitated and released while others die and are kept frozen for later analysis. Sooty terns collected in Juan de Nova all died from cat predation.

We decided to cover a wide range of species in order to capture the variability of the vulnerability to plastic pollution in relation to trophic ecology, foraging behavior, foraging ranges and migration strategies of each species. Samples from Reunion Island were obtained over a period of 14 years (2002–2016) and samples from Juan de Nova over a period of four years (2004–2008). Samples were kept frozen until necropsies were performed in 2016. Before necropsy, birds were defrosted at room temperature. Necropsies were performed by removing the rib cage and pectoral muscles, exposing the abdominal viscera. Body condition of the birds was analyzed by recording the state of the pectoral muscles categorized as "good" (muscles appear convex), "medium" (muscle appear flat) or "poor" (muscles appear concave). The content of the gizzard and proventriculus were then examined for the presence of plastic using a dissecting microscope. Plastics were counted and classified by type: hard plastics, films and fibers (Fig. 1). Items were placed in Eppendorf tubes and dried in an oven at 50 °C for 48 h and then weighed on a digital balance (± 0.00001 g). The color of plastic particles was not recorded.

2.1. Statistical analyses

Data were analyzed using RStudio version 0.99.446 with univariate tests to analyze differences of plastic ingestion rates between species and age classes. Data were analyzed to check for Normality with a Shapiro test. When data were normal we used *t*-tests, ANOVAs and Tukey HSD tests. When data were not normal we used Kruskal Wallis and Pairwise Wilcox tests.

3. Results

Considering all species together, 50% of the birds analyzed had plastic in their gizzard or proventriculus, but there was strong variation in relation to species and age (Figs. 2 and 3). The two most contaminated species were the tropical shearwater (79% of the birds had plastic in their gut, $n = 56$) and the Barau's petrel (63%, $n = 62$), followed by the lesser noddy (43%, $n = 21$), the brown noddy (33% $n = 9$), the wedge-tailed shearwater (33%, $n = 9$), the white-tailed tropicbird (29% $n = 35$) and the sooty tern (15%, $n = 27$). We analyzed only one critically endangered Mascarene petrel and we found plastic in its gut (100%, $n = 1$). Finally, we found one piece of fiber in one of the Cape Gannet analyzed (50%, $n = 2$, Table 1). There was no relation between plastic ingestion and muscular condition.

The average number of plastic particles per contaminated bird was higher in Barau's petrel (6.10 ± 1.29) and tropical shearwaters (3.84 ± 0.59) and lower in other species (Fig. 2). We investigated the effect of age on plastic ingestion of tropical shearwaters, Barau's petrels and white-tailed tropicbirds (Fig. 3). There were no significant differences in the proportion of juveniles and adults having ingested plastic in the three studied species (Barau's petrels: Chi-square = 1.22, $p = 0.269$; tropical shearwaters: Chi-square = 1.59, $p = 0.208$; white-tailed tropicbird: Chi-square = 1.03, $p = 0.310$). The number of particles per contaminated bird was higher in juveniles than in adult Barau's petrels (7.06 ± 1.57 and 2.38 ± 0.8 particles, respectively, $p < 0.001$), tropical shearwaters (4.09 ± 0.62 and 3.33 ± 1.15 respectively, $p = 0.20$), and white-tailed tropicbird (2.67 ± 1.20 and 1.71 ± 0.29 respectively, $p = 0.06$) but the difference was significant for Barau's petrels only.

We also tested differences in the mass of the plastic particles ingested by Barau's petrels, tropical shearwaters and white-tailed tropicbirds. There were no significant differences between species ($p = 0.2735$) but the mass of plastic particles was higher in juveniles than in adults in both tropical shearwaters ($t = 2.1539$, $p = 0.0405$) and Barau's petrels ($t = 2.1109$, $p = 0.0429$, Fig. 4). The number of juveniles and adults having ingested plastic was too low in white-tailed tropicbirds to investigate the effect of age. Regarding the amount and the mass of plastic ingested over time, no significant differences could be observed. This study has only been performed on tropical

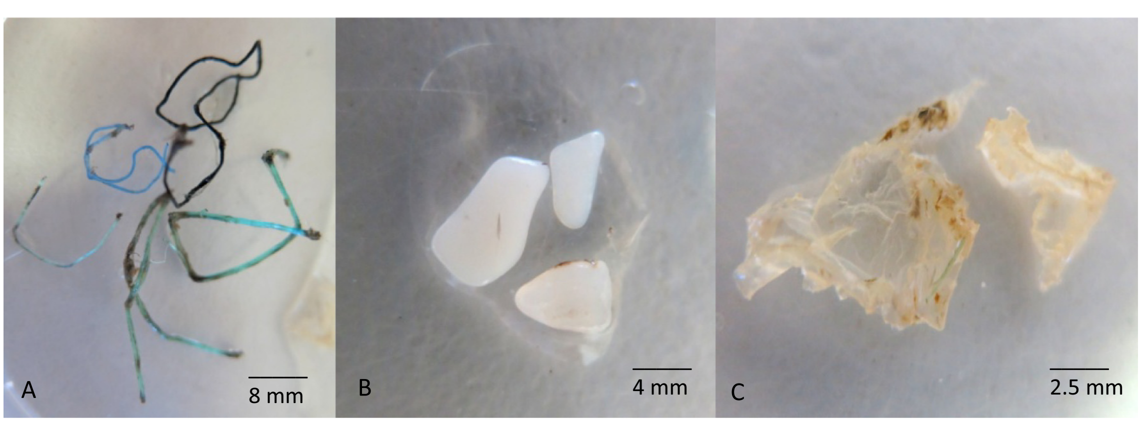

Fig. 1. (A) Plastic fibers, (B) hard fragments and (C) films collected from tropical shearwaters.

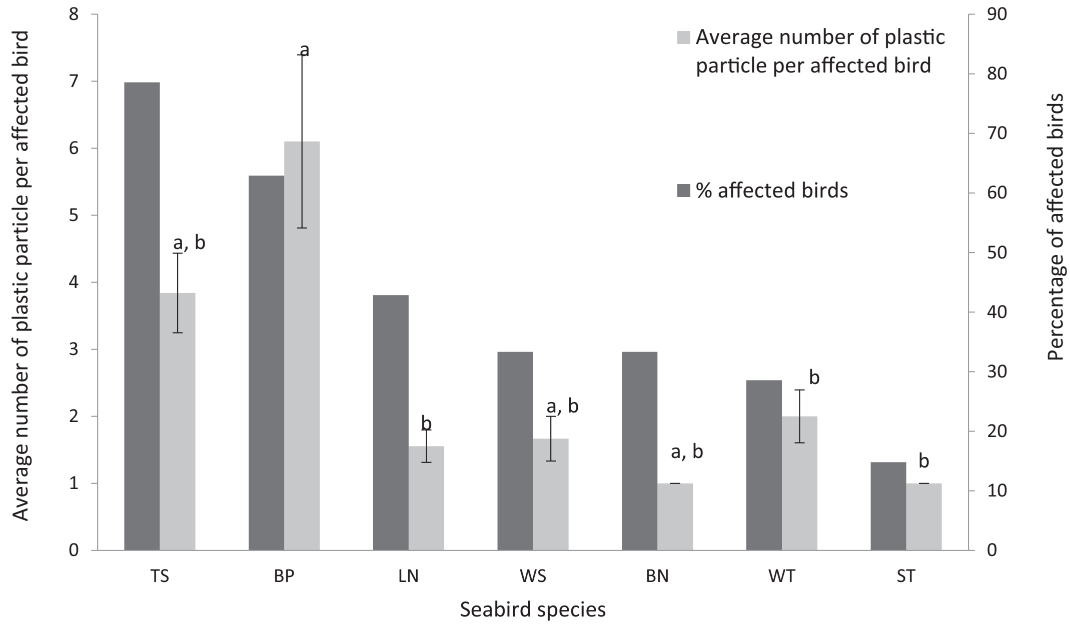

Fig. 2. Percentage of individuals per species having ingested plastic and average number of plastic particles retrieved in affected seabird ± standard error. (TS = tropical shearwater, BP = Barau's petrel, LN = lesser noddy, WS = wedge-tailed shearwater, BN = brown noddy, WT = white-tailed tropicbird, ST = sooty tern). Species with different letters are significantly different from each other.

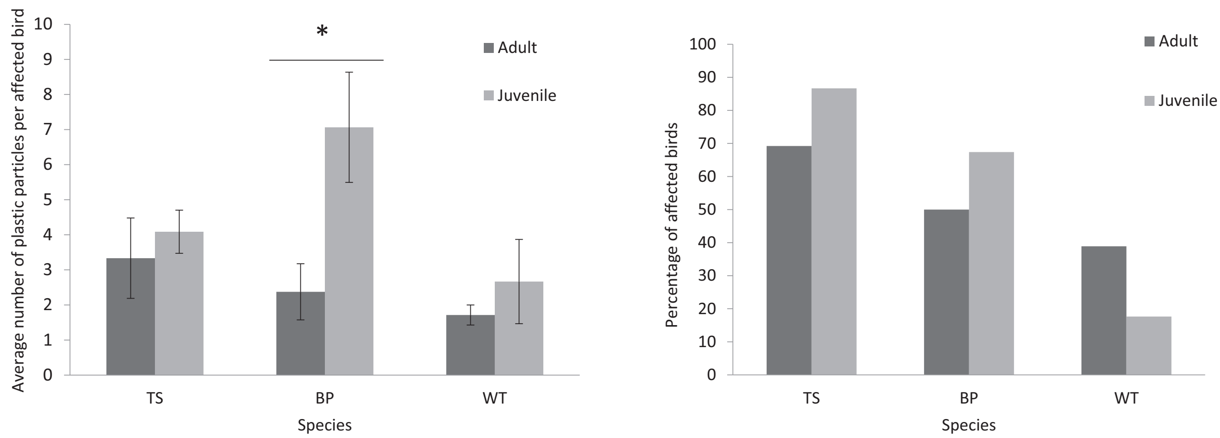

Fig. 3. (A) Average number of plastic particles retrieved in affected juveniles and adults ± standard error and (B) percentage of juveniles and adults per species having ingested plastic. (TS = tropical shearwater, BP = Barau's petrel, WT = white-tailed tropicbird). * represents significant differences.

shearwaters as it was the only species where enough birds were analyzed over time.

Hard plastic fragments, fibers and films were the main debris recorded in this study (Fig. 1). Plastics found were mainly fibers, reaching a total of 100% for sooty terns and brown noddies (Fig. 5). Hard fragments and films also represented an important part of plastics in Barau's petrels with on average 1.56 ± 1.15 and 1.51 ± 1.5 particles per contaminated bird respectively. Hard fragments and films were also present in tropical shearwaters, tropicbirds and the wedge-tailed shearwaters' stomach contents (Fig. 5). There were no significant

Table 1
Seabird species and life stages analyzed in this study.

Common name	Scientific name	Family	Juvenile	Adult	Total
Tropical shearwater	*Puffinus lherminieri*	Procellariidae	30	26	56
Wedge-tailed shearwater	*Ardenna pacifica*	Procellariidae	2	7	9
Barau's petrel	*Pterodroma baraui*	Procellariidae	46	16	62
Mascarene petrel	*Pseudobulweria aterrima*	Procellariidae	0	1	1
White-tailed tropicbird	*Phaethon lepturus*	Phaethontidae	17	18	35
Brown noddy	*Anous stolidus pileatus*	Laridae	0	9	9
Lesser noddy	*Anous tenuirostris*	Laridae	2	19	21
Sooty tern	*Ornithoprion fuscatus*	Laridae	2	25	27
Cape Gannet	*Morus capensis*	Sulidae	2	0	2
Total			101	121	222

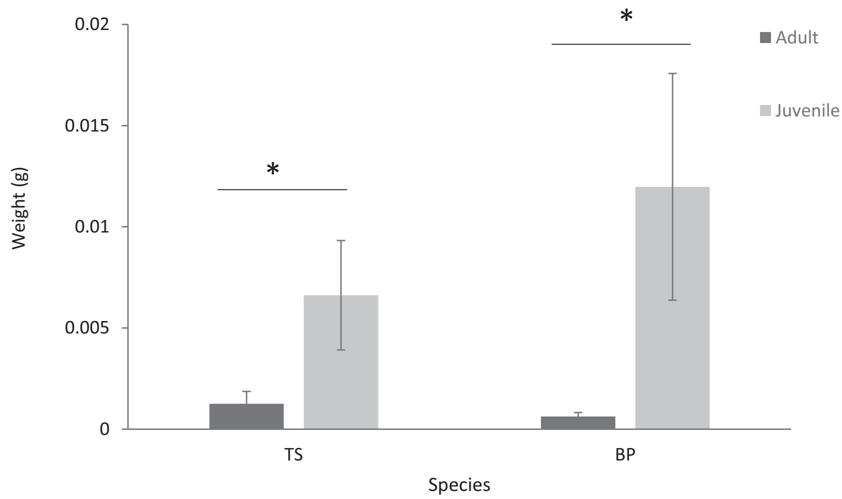

Fig. 4. Average weight of plastic particles retrieved in affected seabird ± standard error. (TS = tropical shearwater, BP = Barau's petrel). * represents significant differences.

differences in the type of plastic ingested in Barau's petrels or tropical shearwaters. No other species could be statistically tested due to low number of birds contaminated by plastic.

4. Discussion

4.1. Species-specific differences in plastic ingestion

Our study shows that the nine seabird species included in this study ingest plastic accidentally or opportunistically when foraging or when fed by their parents, but there were significant differences between species. Tropical shearwater and Barau's petrel were the two most impacted species, both in terms of ingestion occurrence and in terms of number and mass of ingested plastic particles per bird. Petrels and shearwaters are known to ingest plastic frequently in various parts of the world (Azzarello and Van Vleet, 1987; Moser and Lee, 1992; Robards et al., 1995). In the northern Pacific Ocean, 88.5% of sooty shearwater (*Puffinus griseus*) and 81.1% of short-tailed shearwater (*Puffinus tenuirostris*) had ingested plastic particles (Ogi, 1990). Ogi's study also revealed a significant increase in plastic ingestion from 1975 to 1987. More recently, short-tailed shearwaters have been studied on Stradbroke Island in Australia between 2010 and 2012, showing a plastic ingestion rate of 67% (Acampora et al., 2014). Our study shows that it is also the case in the western Indian Ocean. No previous study has been done on plastic ingestion by tropical shearwaters or Barau's petrel, although Danckwerts et al. (2016) noted opportunistically in a study on foraging ecology and diet that 16.7% of the fledglings Barau's petrels had plastic particles in their gut (n = 36 birds analyzed). The level of plastic ingestion was lower in the wedge-tailed shearwater, which may be explained by the fact that we sampled mostly adults (7 out of 9) and adults are known to accumulate less plastic than fledglings (Acampora et al., 2014; Van Franeker and Law, 2015 and this study, Table 2). No conclusions could be drawn regarding muscular condition of the individuals compared to mean number or weight of particles. A recent study recorded similar results on wedge-tailed shearwaters on Lord Howe Island in Australia where there was no obvious influence of ingested plastic on the body condition of the individuals (Lavers et al., 2018).

The fact that petrels and shearwaters have more plastic in their gut may be explained by the presence of a gizzard in the Procellariidae which can accumulate non-digested food items such as squid beaks or plastic particles. The foraging ecology of Procellariidae could also

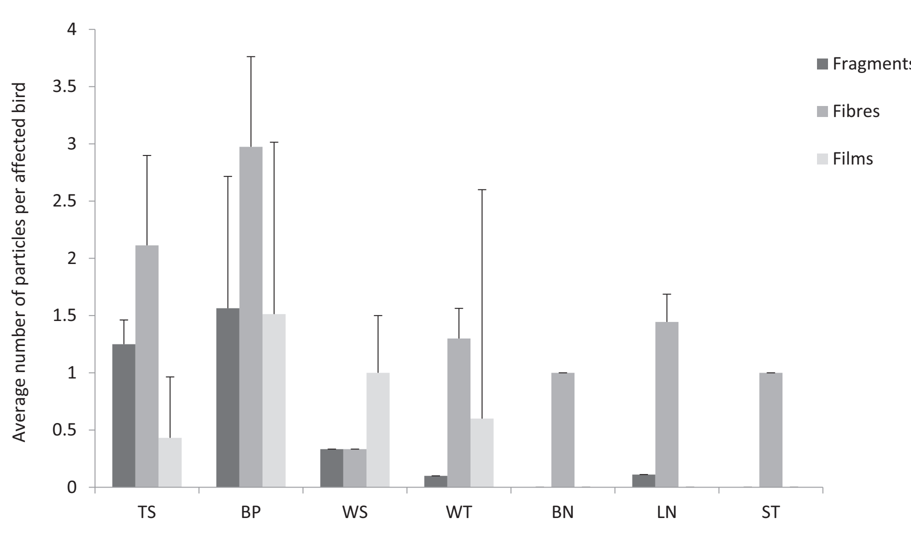

Fig. 5. Average number of fragment, fiber and film particles retrieved in affected seabird ± standard error. (TS = tropical shearwater, BP = Barau's petrel, LN = lesser noddy, BN = brown noddy, WS = wedge-tailed shearwater, WT = white-tailed tropicbird, ST = sooty tern).

Table 2
Previous records of plastic ingestion in white tailed tropicbirds, sooty tern, brown noddy and wedge tailed shearwaters.

Species	Area	Mean number of plastic particles per affected bird	Total weight of plastic particles (g)	Incidence/(n)	Reference
White-tailed tropicbird	O'Ahu, Hawaii	1	15	33% (3)	Hyrenbach et al., 2013
	Réunion	2 ± 0.39	0.00034 ± 0.00021	29% (35)	This study
Brown noddy	Eastern Australia	0	0	0% (1)	Roman et al., 2016
	Réunion	1 ± 0	1.33E−05 ± 3.33E−06	33% (9)	This study
Sooty tern	Eastern Australia	0	0	0% (27)	Roman et al., 2016
	Juan de Nova	1 ± 0	0.000015 ± 2.88E−06	15% (27)	This study
Wedge tailed shearwater	Eastern Australia	N/A	N/A	43% (30)	Hutton et al., 2008
	Eastern Australia	0.46 ± N/A	N/A	14.3% (28)	Roman et al., 2016
	Eastern Australia	3.2 ± 0.32	5.6 ± 1.04	21% (24)	Verlis et al., 2013
	South eastern Australia	1	27.5	50% (2)	Gilbert et al., 2016
	Kaua'i, Hawaii	3.68 ± 9.29 (adults) 2.38 ± 1.94 (fledglings)	220 ± 910 (adults) 30 ± 30 (fledglings)	59.5% (32)	Kain et al., 2016
	Réunion	1.67 ± 0.33	0.0144 ± 0.121	33% (9)	This study

explain this high ingestion rate. Petrels and shearwaters are often scavengers and are susceptible to feed at the surface of the water on dead preys or floating organic fragments and can therefore mistake plastic for preys. Besides, Savoca et al., 2016 suggested that plastic debris emit the scent of marine infochemicals (dimethyl sulfide) creating an olfactory trap for olfactory foraging seabirds such as petrels and shearwaters. The rate of plastic ingestion was less important in the three species of terns studied and on the white-tailed tropicbird, as found in other studies (Hyrenbach et al., 2013; Roman et al., 2016, Table 2). Terns and tropicbirds perform plunge diving to catch their prey and they do not scavenge. This probably reduces the risk of confusion with plastic items (Harrison, 1990).

Furthermore, the different species studied do not forage in the same areas, which may result in different plastic ingestion rates due to different level of plastic pollution in these areas. Tracking studies have been realized in the western Indian Ocean (Pinet et al., 2011; Le Corre et al., 2012; Jaeger et al., 2017; unpublished data) and show different feeding areas and migration patterns for most of the species studied here. Similarly, previous studies have revealed an important plastic difference found in stomach contents of a Fulmar species, *Fulmarus glacialis*, between individuals from Alaska (average of 2.8 particles per stomach) and individuals from California (average of 11.3 particles per stomach). These differences were attributed to different feeding areas, coastal areas in California being more polluted due to high population (Van Franeker and Law, 2015).

4.2. Differences of plastic ingestion in relation to age

Our results show a higher number and a higher mass of plastic particles in juvenile Barau's petrels, compared to adults and a higher mass of plastic particles in juvenile tropical shearwaters compared to adults. These differences are most probably due to food regurgitation from the adults to feed the chicks. Indeed, juveniles do not regurgitate and thus accumulate a large proportion of the plastic particles ingested by adults. Several other studies have shown similar patterns, especially among petrels and shearwaters (Rodriguez et al., 2012; Verlis et al., 2013; Acampora et al., 2013), but also on albatrosses (Rapp et al., 2017).

4.3. Types of ingested particles

In this paper we also briefly analyzed the types of plastic ingested. Seabirds tend to select distinct shapes and colored plastic, confusing it for potential preys (Shaw and Day, 1994). More recent studies showed the type of plastic ingested by seabirds was dependent on the plastic fragment characteristic (UNEP, 2016). In this paper, some species such as *O. fuscatus* or *A. stolidus* showed a distinct attraction for plastic fibers with an ingestion rate reaching 100% compared to other plastic materials. Fibers are also frequently found in every other species and come from the fishing industry (fishing lines and ropes).

4.4. Implications for conservation

Our study shows that the level of plastic ingestion and accumulation is particularly high in the endangered Barau's petrel (and possibly the Critically endangered Mascarene petrel), compared to the other species studied. The impacts of plastic debris on both individual survival and population dynamics are difficult to measure, however other studies have suggested that plastic ingestion may lead to gastrointestinal blockage, reduced storage volume of the stomach or uptake of hazardous chemicals, impacting their reproduction potential and causing mortality (Azzarello and Van Vleet, 1987; Ryan, 1988; Teuten et al., 2009). This is particularly worrying for the endemic petrels of Reunion Island which dynamics is already weakened by invasive predators (Faulquier et al., 2009), light-induced mortality (Le Corre et al., 2002) and possibly global warming (Legrand et al., 2016).

4.5. A call for a long term monitoring of plastic ingestion in the western Indian Ocean

Our study is the first to quantify plastic ingestion in a range of tropical seabird species of the western Indian Ocean. We have shown that in this part of the world the oceanic food webs are polluted by plastic debris and this is very worrying as it may impact a wide range of marine animals. We have also shown that fledgling tropical shearwaters and Barau's petrels are highly impacted. We suggest to use these two species as bioindicator species to monitor plastic pollution in this region. These two species are attracted by artificial light and hundreds of birds are found stranded annually and rescued (Le Corre et al., 2002; Gineste et al., 2017). Although on average 90% of the rescued birds are released successfully, 10% are found dead or die as a consequence of injuries. This represent a regular and predictable number of dead birds, estimated between 50 and 80 fledglings Barau's petrels and 50 to 100 fledgling tropical shearwaters which can be used for necropsies and plastic ingestion monitoring as we did in this study (see also Rodriguez et al., 2017). In the northern hemisphere, the level of plastic ingestion in Northern Fulmars is routinely used by European policies as a long-term indicator of environment quality and plastic pollution (Van Franeker and Law, 2015). The same monitoring should be implemented in the western Indian Ocean and tropical shearwaters and Barau's petrels are very appropriate for such a monitoring (see also Ryan et al., 2009; Rodriguez et al., 2017).

Contributors

Audrey Cartraud: Designed the study, performed the necropsies and analysis and wrote the paper.

Matthieu Le Corre: Designed the study and wrote the paper.

Jean Turquet: Designed the study.

Julie Tourmetz: Managed the collection of the analyzed seabirds.

Declaration of interest

None.

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References

Acampora, H., Schuyler, Q.A., Townsend, K.A., Hardesty, B.D., 2013. Comparing plastic ingestion in juvenile and adult stranded short-tailed shearwaters (*Puffinus tenuirostris*) in eastern Australia. Mar. Pollut. Bull. 78 (1–2), 63–68.

Avery-Gomm, S., O'Hara, P.D., Kleine, L., Bowes, V., Wilson, L.K., Barry, K.L., 2012. Northern fulmars as biological monitors of trends of plastic pollution in the eastern North Pacific. Mar. Pollut. Bull. 64 (9), 1776–1781.

Azzarello, M., Van Vleet, E., 1987. Marine birds and plastic pollution. Mar. Ecol. Prog. Ser. 37, 295–303.

Barnes, D.K.A., 2004. Natural and plastic flotsam stranding in the Indian Ocean. In: Davenport, John, Davenport, Julia L. (Eds.), The Effects of Human Transport on Ecosystems: Cars and Planes, Boats and Trains. Royal Irish Academy, Dublin, pp. 193–205.

Barnes, D.K., Galgani, F., Thompson, R.C., Barlaz, M., 2009. Accumulation and fragmentation of plastic debris in global environments. Philos. Trans. R. Soc. Lond. B Biol. Sci. 364 (1526), 1985–1998.

Bouwman, H., Evans, S.W., Cole, N., Kwet Yive, N.S.C., Kylin, H., 2016. The flip-or-flop boutique: marine debris on the shores of St Brandon's rock, an isolated tropical atoll in the Indian Ocean. Mar. Environ. Res. 114, 58–64.

Copello, S., Quintana, F., 2003. Marine debris ingestion by Southern Giant petrels and its potential relationships with fisheries in the Southern Atlantic Ocean. Mar. Pollut. Bull. 46, 1513–1515.

Danckwerts, D.K., Corre, S., Pinet, P., Le Corre, M., Humeau, L., 2016. Isolation and characterization of 15 polymorphic microsatellite loci for the Barau's petrel (*Pterodroma baraui*), an endangered endemic of Réunion Island (Indian Ocean). Waterbirds 39 (4), 413–416.

Derraik, J.G.B., 2002. The pollution of the marine environment by plastic debris: a review. Mar. Pollut. Bull. 44, 842–852.

Duhec, A.V., Jeanne, R.F., Maximenko, N., Hafner, J., 2015. Composition and potential origin of marine debris stranded in the Western Indian Ocean on remote Alphonse Island, Seychelles. Mar. Pollut. Bull. 96 (1–2), 76–86.

Faulquier, L., Fontaine, R., Vidal, E., Salamolard, M., Le Corre, M., 2009. Feral cats *Felis catus* threaten the endangered endemic Barau's petrel *Pterodroma baraui* at Reunion Island (Western Indian Ocean). Waterbirds 32 (2), 330–336.

Feare, C.J., Jaquemet, S., Le Corre, M., 2007. An inventory of sooty terns (Sterna fuscata) in the western Indian Ocean with special reference to threats and trends. Ostrich 78 (2), 423–434.

Fumess, R.W., 1985. Ingestion of plastic particles by sea-birds at Gough Island, South Atlantic Ocean. Environ. Pollut. Ser. A 38, 261–272.

Gilbert, J.M., Reichelt-Brushett, A.J., Bowling, A.C., Christidis, L., 2016. Plastic ingestion in marine and coastal bird species of Southeastern Australia. Mar. Ornithol. 44, 21–26.

Gineste, B., Souquet, M., Couzi, F.X., Giloux, Y., Philippe, J.S., Hoarau, C., Tourmetz, J., Potin, G., Le Corre, M., 2017. Tropical shearwater population stability at Reunion Island, despite light pollution. J. Ornithol. 158 (2), 385–394.

Harrison, C.S., 1990. Seabirds of Hawaii: Natural History and Conservation. Cornell University Press, Ithaca, New York.

Hoarau, L., Ainley, L., Jean, C., Ciccione, S., 2014. Ingestion and defecation of marine debris by loggerhead sea turtles, Caretta caretta, from by-catches in the south-West Indian Ocean. Mar. Pollut. Bull. 84, 90–96.

Hutton, I., Carlile, N., Priddel, D., 2008. Plastic ingestion by flesh-footed shearwaters, *Puffinus carneipes* and wedge-tailed shearwaters *Puffinus pacificus*. Pap. Proc. R. Soc. Tasmania 142 (1), 67–72.

Hyrenbach, K.D., Hester, M.M., Johnson, J.A., Lyday, S., Bingham, S., Pawloski, J., 2013. First evidence of plastic ingestion by white-tailed tropicbirds from O'ahu, Hawai'i. Mar. Ornithol. 41, 167–169.

Jaeger, A., Feare, C.J., Summes, R.W., Lebarbenchon, C., Larose, C.S., Le Corre, M., 2017. Geolocation reveals year-round at-sea distribution and activity of a superabundant tropical seabird, the sooty tern *Onychoprion fuscatus*. Front. Mar. Sci. 4, 394.

Kain, E., Lavers, J.L., Berg, C., Raine, A.F., Bond, A.L., 2016. Plastic ingestion by Newell's (*Puffinus newelli*) and wedge-tailed shearwaters (*P. pacificus*) in Hawaii. Environ. Sci. Pollut. Res. 23, 23951–23958.

Lavers, J.L., Bond, A.L., Hutton, I., 2014. Plastic ingestion by flesh-footed shearwaters (*Puffinus carneipes*): implications for fledgling body condition and the accumulation of plastic-derived chemicals. Environ. Pollut. 187, 124–129.

Lavers, J.L., Hutton, I., Bond, A.L., 2018. Ingestion of marine debris by wedge-tailed shearwaters (*Ardenna pacifica*) on Lord Howe Island, Australia during 2005–2018. Mar. Pollut. Bull. 133, 616–621.

Le Corre, M., Ollivier, A., Ribes, S., Jouventin, P., 2002. Light-induced mortality of petrels: a 4-year study from Réunion Island (Indian Ocean). Biol. Conserv. 105 (1), 93–102.

Le Corre, M., Jaeger, A., Pinet, P., Kappes, M.A., Weimerskirch, H., Catry, T., Ramos, J.A., Russell, J.C., Shah, N., Jaquemet, S., 2012. Tracking seabirds to identify potential marine protected areas in the tropical western Indian Ocean. Biol. Conserv. 156, 83–93.

Legrand, B., Benneveau, A., Jaeger, A., Pinet, P., Potin, G., Jaquemet, S., Le Corre, M., 2016. Current wintering habitat of an endemic seabird of Réunion Island, Barau's petrel *Pterodroma baraui*. Mar. Ecol. Prog. Ser. 550, 235–248.

Moser, M.L., Lee, D.S., 1992. A fourteen years survey of plastic ingestion by western North Atlantic seabirds. Colon Waterbirds 15, 83–94.

Ogi, H., 1990. In: Shomura, K.S., Godfrey, M.L. (Eds.), Proceedings of the Second International Conference on Marine Debris, 2–7 April 1989. Honolulu, Hawaii. U.S.

Pinet, P., Jaquemet, D., Pinaud, D., Weimerskirch, H., Phillips, R.A., Le Corre, M., 2011. Migration, wintering distribution and habitat use of an endangered tropical seabird, Barau's petrel *Pterodroma baraui*. Mar. Ecol. Prog. Ser. 423, 291–302.

Plastics Europe, 2013. Plastics - The Facts 2013: An Analysis of European Latest Plastics Production, Demand, and Waste Data (Plastics Europe, Brussels).

Rapp, D.C., Youngren, S.M., Hartzell, P., Hyrenbatch, K.D., 2017. Community-wide patterns of plastic ingestion in seabirds breeding at French Frigate Shoals, Northwestern Hawaiian Islands. Mar. Pollut. Bull. 123, 269–278.

Robards, M.D., Piatt, J.F., Wohl, K.D., 1995. Increasing frequency of plastic particles ingested by seabirds in the subarctic North Pacific. Mar. Pollut. Bull. 30, 151–157.

Rodriguez, A., Rodriguez, B., Curbelo, A.J., Perez, A., Marrero, S., Negro, J.J., 2012. Factors affecting mortality of shearwaters stranded by light pollution. Anim. Conserv. 15 (5), 519–526.

Rodriguez, A., Holmes, M.D., Ryan, P.G., Wilson, K.J., Faulquier, L., Murillo, Y., Raine, A.F., Penniman, J.F., Neves, V., Rodriguez, B., Negro, J.J., Chiaradia, A., Dann, P., Anderson, T., Metzger, B., Shirai, M., Deppe, L., Wheeler, J., Hodum, P., Gouveia, C., Carmo, V., Carreira, G.P., Delgado-Alburqueque, L., Guerra-Correa, C., Couzi, F.X., Travers, M., Le Corre, M., 2017. Seabird mortality induced by land-based artificial lights. Conserv. Biol. 31 (5), 986–1001.

Roman, L., Schuyler, Q.A., Hardesty, B.D., Townsend, K.A., 2016. Anthropogenic debris ingestion by avifauna in Eastern Australia. PLoS One 11 (8), 1–14.

Ryan, P.G., 1987. The incidence and characteristics of plastic particles ingested by seabird. Mar. Environ. Res. 23, 175–206.

Ryan, P.G., 1988. Effects of ingested plastic on seabird feeding: evidence from chickens. Mar. Pollut. Bull. 19 (3), 125–128.

Ryan, P.G., 2015. How quickly do albatrosses and petrels digest plastic particles? Environ. Pollut. 207, 438–440.

Ryan, P.G., Moore, C.J., Van Franeker, J.A., Moloney, C.L., 2009. Monitoring the abundance of plastic debris in the marine environment. Philos. Trans. R. Soc. Lond. B Biol. Sci. 364 (1526), 1999–2012.

Ryan, P.G., Nico De Bruyn, P.J., Bester, M.N., 2016. Regional differences in plastic ingestion among southern ocean fur seals and albatrosses. Mar. Pollut. Bull. 104, 207–210.

Salamolard, M., Ghestemme, T., Couzi, F., Minatchy, N., Le Corre, M., 2007. Impacts des éclairages urbains sur les pétrels de Barau, Pterodroma baraui, sur l'Ile de la Réunion et mesures pour réduire ces impacts. Ostrich 78, 449–452.

Savoca, M.S., Wohlfeil, M.E., Ebeler, S.E., Nevitt, G.A., 2016. Marine plastic debris emit a keystone infochemical for olfactory foraging seabirds. Sci. Adv. 2, e1600395.

Shaw, D.G., Day, R.H., 1994. Colour- and form-dependent loss of plastic micro-debris from the North Pacific Ocean. Mar. Pollut. Bull. 28, 39–43.

Spear, L.B., Ainley, D.G., Ribic, C.A., 1995. Incidence of plastic in seabirds from the tropical Pacific, 1984–91: relation with distribution of species, sex, age, season, year and body weight. Mar. Environ. Res. 40, 123–146.

Talsness, C.E., Andrade, A.J.M., Kuriyama, S.N., Taylor, J.A., Vom Saal, F.S., 2009. Component of plastics: experimental studies in animals and relevance for human health. Philos. Trans. R. Soc. B Biol. Sci. 364, 2079–2096.

Teuten, E.L., Saquing, J.M., Knappe, D.R.U., Barlaz, M.A., Jonsson, S., Bjorn, A., Rowland, S.J., Thompson, R.C., Galloway, T.S., Yamashita, R., Ochi, D., Watanuki, Y., Moore, C., Viet, P.H., Seang Tana, T., Prudente, M., Boonyatumanond, R., Zacharia, M.P., Akkhavong, K., Ogata, Y., Hirai, H., Iwasa, S., Mizukawa, K., Hagino, Y., Imamura, A., Saha, M., Takada, H., 2009. Transport and release of chemicals from plastics to the environment and to wildlife. Philos. Trans. R. Soc. B Biol. Sci. 364, 2027–2045.

United Nations Environmental Programme (UNEP), 2016. Marine Plastic Debris and Microplastics – Global Lessons and Research to Inspire Action and Guide Policy Change. United Nations Environment Programme, Nairobi.

Van Franeker, J., Law, L.K., 2015. Seabirds, gyres and global trends in plastic pollution. Environ. Pollut. 203, 89–96.

Verlis, K.M., Campbell, M.L., Wilson, S.P., 2013. Ingestion of marine debris plastic by the wedge-tailed shearwater *Ardenna pacifica* in the Great Barrier Reef, Australia. Mar. Pollut. Bull. 72 (1), 244–249.

Verlis, K.M., Campbell, M.L., Wilson, S.P., 2014. Marine debris is selected as nesting material by the brown booby (*Sula leucogaster*) within the Swain Reefs, Great Barrier Reef, Australia. Mar. Pollut. Bull. 87, 180–190.

Verlis, K.M., Campbell, M.L., Wilson, S.P., 2018. Seabirds and plastic don't mix: examining the differences in marine plastic ingestion in wedge-tailed shearwaters chicks at near-shore and offshore locations. Mar. Pollut. Bull. 135, 852–861.

Wilcox, C., Van Sebille, E., Hardesty, B.D., 2015. Threat of plastic pollution to seabirds is global, pervasive, and increasing. PNAS 112 (38), 11899–11904.

Yamashita, R., Takada, H., Fukuwaka, M.A., Watanuki, Y., 2011. Physical and chemical effects of ingested plastic debris on short-tailed shearwaters, *Puffinus tenuirostris*, in the North Pacific Ocean. Mar. Pollut. Bull. 62, 2845–2849.