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Review

Ingestion of marine debris by the White-chinned Petrel (*Procellaria aequinoctialis*): Is it increasing over time off southern Brazil?

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ABSTRACT

Seabirds are amongst the most affected organisms by plastic pollution worldwide. Ingestion of marine debris has been reported in at least 122 species, and owing to the increasing global production and persistence of these anthropogenic materials within the marine environment, it is expected to be a growing problem to the marine fauna. Here we report evidence of an increasing frequency in marine debris ingestion and a decrease in the amount of plastic pellets ingested by White-chinned Petrels attending south Brazilian waters during the last three decades. Future studies comprising large temporal scales and large sample sizes are needed to better understand the trends of marine debris ingestion by seabirds. We expect our findings to highlight the need for prevention policies and mitigation measures to reduce the amount of solid litter in the oceans.

1. Introduction

Ocean pollution by debris has been one of the main concerns of marine ecologists over the past decades, especially because of its increasing rate as the production of plastic is rising exponentially (Plastics Europe, 2012; Wilcox et al., 2015). The most abundant man-made debris within the marine environment are plastic fragments and pellets: buoyant synthetic organic polymers that disperse over long distances and tend to accumulate in convergence zones and oceanic gyres, forming large garbage patches on the sea surface (Barnes et al., 2009). Major concentrations of plastic debris are found in all five convergence zones and along coasts near human occupation (Cózar et al., 2014; Eriksen et al., 2014). The South Atlantic Gyre in the Atlantic Ocean and the coast of south Brazil present high levels of debris accumulation (Eriksen et al., 2014; Van Sebille et al., 2015; Petersen et al., 2016).

Although there is little knowledge and lack of evidence on how the ingestion of marine debris may cause direct ecological impacts upon the marine fauna at the population level (Rochmann et al., 2016), harmful health effects resulting from both ingestion and entanglement have been described to affect individuals of marine vertebrate taxa such as seabirds, sea turtles, and marine mammals (Azzarello and Van Vleet, 1987; Laist, 1987; Bugoni et al., 2001; Derraik, 2002; Pierce et al., 2004; Jacobsen et al., 2010). Ingestion and entanglement are the most conspicuous, frequent, and harmful consequences of marine debris pollution to the marine fauna. For instance, Gall and Thompson (2015) reported an increase from 267 (Laist, 1997) to 395 in the number of marine species affected by ingestion of and entanglement by marine debris over the past two decades. However, we should consider that gaps in Laist's review may have biased an exaggerated increase in the number of species recorded in Gall and Thompson's review. Entanglement in loops and openings of floating materials, such as fishing gear, may lead to death by drowning, because of difficulty in foraging and avoiding predators, or because of the aggravation of wounds caused by sharp edged and abrasive debris (Laist, 1987, 1997; Gregory, 2009). Ingestion of plastic is the second-most harmful impact of debris pollution on the marine fauna (Gall and Thompson, 2015). The major consequences reported to affect seabirds are internal injuries and obstruction of the digestive tract, blockage of gastric enzyme secretion, and reduction in feeding stimulus, which eventually could lead to death by starvation (Furness, 1985; Azzarello and Van Vleet, 1987; Ryan et al., 1988; Pierce et al., 2004). Furthermore, plastic debris have been found to accumulate contaminants such as polychlorinated biphenyls (PCBs) and organochlorine pesticides (OCPs) because of their hydrophobic nature and therefore may be a potential source of contamination to organisms that have ingested them (Ryan et al., 1988; Colabuono et al., 2010).

The White-chinned Petrel (*Procellaria aequinoctialis*) breeds in sub-Antarctic islands in the austral summer and disperses northward post breeding, reaching subtropical waters during winter (Phillips et al., 2006). This species is considered as vulnerable according to the IUCN Red List as its global population trend is believed to be decreasing, threatened mostly by interaction with longline fisheries, breeding habitat degradation, and nest predation by introduced species in breeding colonies. Although plastic ingestion is not listed as a factor leading to

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the species conservation status because of the lack of evidence of its adverse effects at the population level, plastic ingestion is mentioned as a threat to White-chinned Petrels by BirdLife International (2016) because of its high frequency of occurrence (FO) (Ryan, 2008; Colabuono et al., 2009). We investigated the FO and amount of marine debris ingested by White-chinned Petrels attending south Brazilian waters during the past three decades.

2. Material and methods

2.1. Sampling

We conducted surveys once a month during three distinct periods, in 1990, from 1997 to 1998, and from 2007 to 2014, comprising 106 surveys over 11 years. A 120-km stretch of sandy beach was covered between Balneário Pinhal (30°15′S, 50°14′W) and Mostardas (31°11′S, 50°50′W) in the mid-coastal region of Rio Grande do Sul state in southern Brazil. All dead beached White-chinned Petrels found along the sandy beach were identified, and their stomachs and gizzards were collected and analyzed in laboratory (n = 114).

2.2. Content analysis

All anthropogenic solid materials found in the stomach contents were counted and separated into virgin and user plastics. Virgin plastics (industrial pellets) are small and spherical raw plastic material, often granules of approximately 4-mm diameter. User plastics are any manufactured plastic material, which includes the following subtypes: fragmented pieces of both rigid and malleable plastic objects, nylon lines, synthetic sponges, styrofoam, ropes, and synthetic rubber fragments (Provencher et al., 2017).

2.3. Statistical analysis

We calculated the relative FO (FO%) of debris ingestion by White-chinned Petrel in the three periods and in each year of study (number of stomachs collected: 1990 = 14; 1997–1998 = 35; 2007–2008 = 65). A simple linear regression was calculated using the annual FO% of stomachs containing debris in each year of study as the response variable to the temporal series to assess the trend of the debris ingestion frequency over time. In addition, we conducted a power analysis following Provencher et al. (2015) to assess the sample size required for detecting a consistent trend of debris ingestion over time. To investigate changes in the intensity (number of items per stomach, considering only individuals presenting debris) of debris ingested by White-chinned Petrels over time, we performed generalized Poisson regression models (GLM) using the count numbers of both industrial and user plastics ingested by each individual, sorted chronologically, as the response variable in a chronological series. Statistical analyses were performed using R ver. 3.3.1 (R Core Team, 2016).

3. Results

3.1. Frequency of ingestion

We found evidence of an increasing FO of marine debris ingestion by the White-chinned Petrel over the last three decades in southern Brazil (Fig. 1). The latest period, from 2007 to 2014, presented the highest frequency of total marine debris ingestion (FO% = 63.07), followed by 1997–1998 (FO% = 42.85) and 1990 (FO% = 21.42). The FO of user plastics ingested also increased over the three periods (1990 = 14.28%; 1997–1998 = 37.14%; 2007–2014 = 61.54%), and the ingestion of virgin plastics showed similar frequencies in all periods (1990 = 14.28%; 1997–1998 = 11.42%; 2007–2014 = 16.92%). The most frequent items found were plastic fragments, which include both hard and malleable pieces of plastic objects (Table 1).

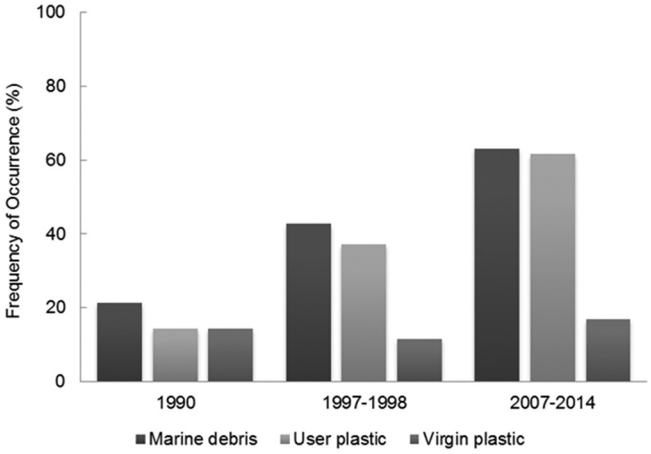

Fig. 1. Frequency of occurrence of total marine debris and user and virgin plastics in the three periods of study.

A significant positive correlation was found between the frequency of marine debris ingestion and the temporal series (r^2 = 0.486; slope = 2.482; $p < 0.05$), suggesting that the frequency of marine debris ingestion by White-chinned Petrels attending south Brazilian waters is increasing over time. Although our results suggested an increasing trend in marine debris ingestion, the power analysis indicated that we lacked the ability to detect a suitable trend of ingestion because of the small sample size. The power analysis showed that to achieve a statistical power of 0.90 (π 90) at a 0.05 significance level (α = 0.05), the sample size required is 169 White-chinned Petrels collected per year for detecting a change of 25% in the frequency of debris ingestion (Fig. 2).

3.2. Intensity of ingestion

User plastic fragments were the most abundant items found in the stomachs of White-chinned Petrels in all three periods of our study, totaling 379 fragments. Virgin pellets (n = 86) were also abundant items in all periods. Nylon lines (n = 46) were absent in 1990 but became abundant in the latest period (2007–2014). Styrofoam (n = 36), synthetic sponges (n = 3), ropes (n = 1), and rubber (n = 3) occurred sporadically and in lower abundances. The intensity of user plastics ingested per individual showed neither positive nor negative relationship with the temporal series (r^2 = 0.016), whereas the intensity of virgin plastic showed a slight decreasing trend (r^2 = 0.221; $p < 0.001$) (Fig. 3). Averages, standard deviations, and FOs of each category are listed in Table 1. Previous studies on debris ingestion by White-chinned Petrels in the Southern Hemisphere are listed in Table 2.

4. Discussion

Ingestion of marine debris by the White-chinned Petrel has been reported since the 1980s, occurring in different frequencies over time and amongst studied regions, although most studies present small sample sizes (Table 2). User plastic fragments are the predominant items found in seabirds' stomach contents in most studies conducted recently. This trend is true not only for the White-chinned Petrel but also for most species of Procellariiformes worldwide (Barbieri, 2009; Colabuono et al., 2009; Provencher et al., 2009; Petry et al., 2010; Codina-García et al., 2013; Verlis et al., 2013; Valls et al., 2015). The ingestion of virgin pellets by White-chinned Petrels increased in frequency during the three decades of our study, but decreased significantly in amount per stomach. Although virgin pellets used to predominate over user plastics in earlier studies, there seems to be a change in the composition of plastic debris ingested by these marine predators over the past two decades (Furness, 1983; Vlietstra and Parga, 2002; Petry et al., 2008; Ryan, 2008). This may be a result of changes in the composition of plastic debris available

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